BS EN 13384-2:2015

BSI Standards Publication

Chimneys — Thermal and fluid dynamic calculation methods

Part 2: Chimneys serving more than one heating appliance

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National foreword

This British Standard is the UK implementation of EN 13384-2:2015. It supersedes BS EN 13384-2:2003+A1:2009 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/506, Chimneys.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Chimneys - Thermal and fluid dynamic calculation methods - Part 2: Chimneys serving more than one heating appliance

Conduits de fumée - Méthodes de calcul thermo-aéraulique - Partie 2: Conduits de fumée desservant plus d'un appareil de chauffage

Abgasanlagen - Wärme- und strömungstechnische Berechnungsverfahren - Teil 2: Abgasanlagen mit mehreren Feuerstätten

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Contents

Page

Foreword

This document (EN 13384-2:2015) has been prepared by Technical Committee CEN/TC 166 “Chimneys”, the secretariat of which is held by ASI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2015, and conflicting national standards shall be withdrawn at the latest by October 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13384-2:2003+A1:2009.

According to EN 13384-2:2003+A1:2009 the following fundamental changes are given:

— editorial mistakes have been corrected;

— mistakes in formulas have been corrected;

— characteristic values for heating appliances for solid fuel and for liquid fuels in Annex B have been adapted to actual data;

— for the mixture of fuels a clarification about the rise of the dew point has been added;

— for non-concentric ducts the calculation of the mean temperature of the air supply has been amended;

— the process for iteration for appliances with low impact of the pressure to the flue gas mass flow (e.g. CHP with combustion engine) has been simplified;

— for chimney fans a calculation procedure has been added;

This standard is one of a series of standards prepared by CEN/TC 166 comprising product standards and execution standards for chimneys.

National installation rules are not regarded in the standard.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This European Standard “Chimneys — Thermal and fluid dynamic calculation methods” consists of three Parts:

— Part 1: Chimneys serving one heating appliance

— Part 2: Chimneys serving more than one heating appliance

— Part 3: Methods for the development of diagrams and tables for chimneys serving one heating appliance

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The calculation described in this standard is complex and is intended to be solved by using a computer programme. The general principles of this calculation method of EN 13384-1 also apply to this standard.

This standard is in support of the execution standards for a chimney installation serving more than one heating appliance.

The execution standard identifies limitations and safety considerations associated with the design, installation, commissioning and maintenance of a chimney serving more than one heating appliance (not dealt within the calculation method).

1 Scope

This part of EN 13384 specifies methods for calculation of the thermal and fluid dynamic characteristics of chimneys serving more than one heating appliance.

This part of EN 13384 covers both the cases, either

a) where the chimney is connected with more than one connecting flue pipe from individual or several appliances in a multi-inlet arrangement; or

b) where the chimney is connected with an individual connecting flue pipe connecting more than one appliance in a cascade arrangement.

The case of multiple inlet cascade arrangement is covered by the case a).

This part of EN 13384 deals with chimneys operating under negative pressure conditions (there can be positive pressure condition in the connecting flue pipe) and with chimneys operating under positive pressure conditions and is valid for chimneys serving heating appliances for liquid, gaseous and solid fuels.

This part of EN 13384 does not apply to:

— chimneys with different thermal resistance or different cross-section in the various chimney segments. This part does not apply to calculate energy gain;

— chimneys with open fire places, e.g. open fire chimneys or chimney inlets which are normally intended to operate open to the room;

— chimneys which serve different kinds of heating appliances regarding natural draught, fan assisted, forced draught or combustion engine. Fan assisted appliances with draught diverter between the fan and the chimney are considered as natural draught appliances;

— chimneys with multiple inlets from more than 5 storeys. (This does not apply to balanced flue chimney.);

— chimneys serving heating appliances with open air supply through ventilation openings or air ducts, which are not installed in the same air supply pressure region (e.g. same side of building).

For positive pressure chimneys this part only applies if any heating appliance which is out of action can be positively isolated to prevent flue gas back flow.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1443:2003, *Chimneys - General requirements*

EN 13384-1:2015, *Chimneys - Thermal and fluid dynamic calculation methods - Part 1: Chimneys serving one appliance*

EN 15287-1:2007+A1:2010, *Chimneys - Design, installation and commissioning of chimneys - Part 1: Chimneys for non-roomsealed heating appliances*

EN 15287-2:2008, *Chimneys - Design, installation and commissioning of chimneys - Part 2: Chimneys for roomsealed appliances*

prEN 16475-2, *Chimneys - Accessories - Part 2: Chimney fans - Requirements and test methods*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1443:2003, EN 13384-1:2015, EN 15287-1:2007+A1:2010, EN 15287-2:2008 and the following apply.

3.1
chimney segment
part of a chimney between two consecutive flue gas connections or between the last flue gas connection and the chimney outlet

3.2
collector segment
part of a connecting flue pipe between two consecutive flue gas connections or between the last flue gas connection and the chimney inlet

3.3
flue gas mass flow
$\dot{m}$
mass of the flue gas leaving the heating appliance through the connecting flue pipe per unit of time

Note 1 to entry: In case of a chimney serving more than one heating appliance, the air being transported through an appliance which is out of action is also given the term flue gas mass flow.

3.3.1
declared flue gas mass flow
$\dot{m}_{\mathrm{W,j}}$
flue gas mass flow given by the manufacturer of the heating appliance j with respect to the heat output used in the calculation

3.3.2
calculated flue gas mass flow
$\dot{m}_{\mathrm{Wc,j}}$
flue gas mass flow calculated with respect to calculated draught and the working conditions of the heating appliance j

3.4
calculated flue gas temperature
$T_{\mathrm{Wc,j}}$
flue gas temperature at the outlet of the heating appliance j depending on the calculated flue gas mass flow

3.5
calculated draught of the flue gas of the heating appliance
$P_{\mathrm{Wc,j}}$
draught at the flue gas outlet of the heating appliance j depending on the calculated flue gas mass flow

3.6
flue damper
device to close or partially close the flue

3.7
balanced flue chimney
chimney where the point of air entry to the combustion air duct is adjacent to the point of discharge of combustion products from the flue, the inlet and outlet being so positioned that wind effects are substantially balanced

3.8
cascade arrangement
arrangement where two or more appliances situated in the same space are connected by a common connecting flue pipe to the chimney

3.9
multi inlet arrangement
arrangement where two or more appliances are connected to the chimney by individual connecting flue pipes

3.10
air duct
independent duct in a building or a structural part of a flue terminal conveying combustion air to a room-sealed appliance

3.11
pressure equalizing opening
opening or duct that directly connects the air duct with the flue at its base

4 General symbols and abbreviations

Symbols, terminology and units are given to make the text of this standard understandable. A list of general symbols and abbreviations is given in EN 13384-1 Indices added to symbols for purposes of the calculation method for chimneys serving more than one heating appliance relate to one chimney segment and/or connection flue pipe section. An example of an indices numbering scheme is given in Figures 1 and 2. Indices numbering shall begin at the lowest, farthest appliance connection. For more than one cascade system/connection, the indices numbering scheme for the calculation formula should be adopted in a similar manner to that for a single cascade scheme. Symbols assigned to a specific section will be indicated by the number of the section after the comma (e. g. $H_{,1}$ is the effective height of a section of a chimney segment between the outlet of the connecting flue pipe of the heating appliance in the lowest position and the outlet of the connecting flue pipe of the next heating appliance).

Each symbol and abbreviation is explained at the formula where it is used.

5 Calculation method

5.1 General principles

The calculation is based upon determining the mass flow distribution in the chimney which fulfils the pressure equilibrium condition (Formula (1)) at each flue gas inlet to the chimney (see Figure 1). After such a distribution has been found four requirements shall be verified:

a) the mass flow requirement (Formulas (4) and (5))

b) the pressure requirement for minimum draught or maximum positive pressure (Formulas (6) or (6b) and (6c))

c) the pressure requirement for maximum draught or minimum positive pressure (Formulas (6a) or (6d))

d) the temperature requirement (Formula (7))

NOTE 1 The calculation is affected by the specific installation design. For recommendations for the installation of appliance and connection flue pipes see Annex A.

NOTE 2 The pressure requirements for maximum draught or minimum positive pressure are only required if there is a limit for the maximum draught for the (negative pressure) heating appliance or a minimum differential pressure of the (positive pressure) heating appliance.

In order to verify the criteria two sets of external conditions are used:

— the calculation of the minimum draught and maximum positive pressure (draught) is made with conditions for which the capacity of the chimney is minimal (i.e. high outside temperature); and also

— the calculation of the maximum draught and minimum positive pressure and of the inner wall temperature with conditions for which the inside temperature of the chimney is minimal (i.e. low outside temperature).

The validation of the mass flow requirement and pressure requirement shall be done at following working conditions, using the external and ambient air temperatures specified in EN 13384-1.

— All heating appliances are simultaneously operating at nominal heat output.

— All heating appliances are simultaneously operating at minimum heat output

— A single heating appliance operating at nominal heat output and all other appliances out of action (all possible cases)

— A single heating appliance operating at minimum heat output and all other appliances out of action (all possible cases)

For positive pressure chimneys a single heating appliance operating at minimum nominal heat output and all other appliances operating at maximum nominal heat output (all possible cases) If the control of the installation guarantees that not all appliances will be in operation simultaneously, the validation of the mass flow requirement and pressure requirement may be done with the maximum number of appliances which will be in operation under the most adverse condition.

The validation for the mass flow requirement and pressure requirement for working conditions with heating appliances at minimum heat output is not required in the following cases:

— the heating appliances do not have any heat output range

— the heating appliances have a heat output which is limited to a fixed value as specified on a label on the appliance. In this case the nominal heat output is the given heat output on the label.

— heating appliances heated with solid fuels without fan and appliances with regulated air supply.

The validation of the mass flow requirement for working conditions with appliances at nominal heat output is not required in the following case:

— the heating appliances have a flue gas mass flow at minimum heat output higher than or equal to the flue gas mass flow at nominal heat output.

The temperature requirement shall be validated for the following relevant working condition, using the ambient and external air temperatures as specified in EN 13384-1:

— heating appliances for solid fuels without fan and heating appliances with regulated air supply are in operation at nominal heat output,

— heating appliances with a draught diverter which provide domestic hot water only are out of action. These heating appliances operate with a considerable secondary air (These operate only a short time and therefore it can be assumed that condensation will not cause damage or a lack in safety);

— heating appliances with a fixed output range are in operation at this (nominal) heat output;

— all other heating appliances are in operation at minimum heat output.

When chimneys suitable for operating under wet conditions are located inside a building the check of the temperature requirement is necessary only for the top of the chimney.

The validation of the temperature requirement is not necessary when the chimney serves only domestic gas fired water heaters with instantaneous production and domestic gas fired storage water heaters.

If the chimney system includes a draught regulator, the system is handled as a cascade system.

5.2 Pressure equilibrium condition

5.2.1 Negative pressure chimneys

The following formulas shall be fulfilled for each chimney segment j at all relevant working conditions:

$$\left| P_{Z,j} - P_{Ze,j} \right| \leq 0{,}1 \text{, in Pa} \quad (1)$$

$$P_{Z,j} = -P_L + \sum_{k=j}^{N} \left(P_{H,k} - P_{R,k} \right) \text{, in Pa} \quad (2)$$

$$P_{Ze,j} = P_{Wc,j} + P_{V,j} + P_{Bc,j} \text{, in Pa} \quad (3)$$

where

$P_{Z,j}$ draught at the flue gas inlet to the chimney segment j, in Pa

$P_{H,k}$ theoretical draught due to chimney effect in chimney segment k, in Pa

$P_{R,k}$ pressure resistance of the chimney segment k, in Pa

$P_{Wc,j}$ calculated draught of the heating appliance, in Pa

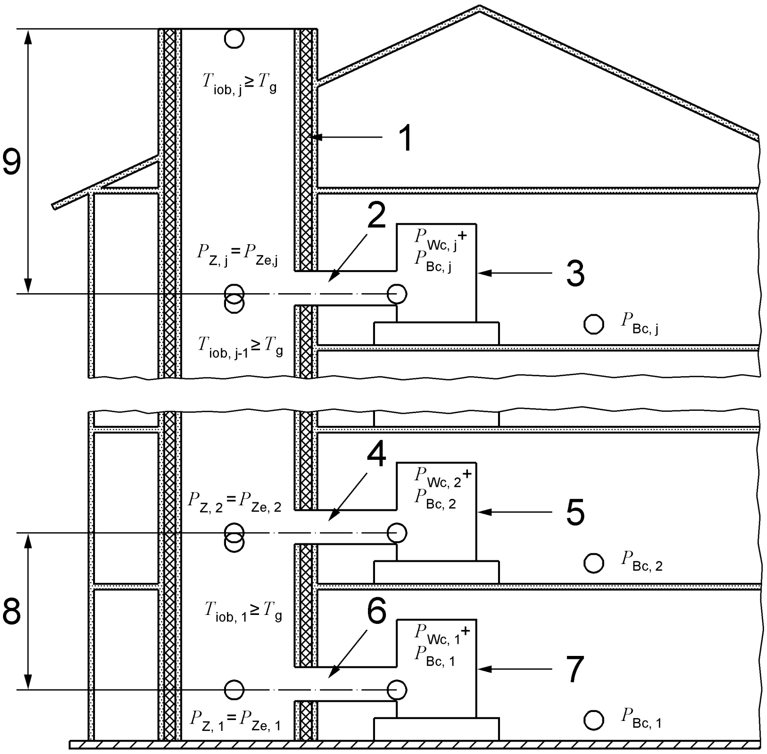
$P_{V,j}$ calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa

$P_{Bc,j}$ calculated pressure resistance of the air supply for the heating appliance j, in Pa

$P_{Ze,j}$ required draught at the flue gas inlet to the chimney segment j, in Pa

P_L wind velocity pressure, in Pa

N number of heating appliances



Key

1 chimney

2 connecting flue pipe j

3 heating appliance j

4 connecting flue pipe 2

5 heating appliance 2

6 connecting flue pipe 1

7 heating appliance 1

8 chimney segment 1

9 chimney segment j

Figure 1 — Example of multiple inlet arrangement and numbering pressure values and temperature values of a chimney serving more than one heating appliance

5.2.2 Positive pressure chimneys

The following formulas shall be fulfilled for each chimney segment j at all relevant working conditions:

$$\left| P_{\text{ZOe},j} - P_{\text{ZO},j} \right| \leq 0{,}1, \text{ in Pa} \quad (3a)$$

$$P_{\text{ZO},j} = P_{\text{L}} + \sum_{k=j}^{N} (P_{\text{R,k}} - P_{\text{H,k}}), \text{ in Pa} \quad (3b)$$

$$P_{\text{ZOe,j}} = P_{\text{WOc,j}} - P_{\text{V,j}} - P_{\text{Bc,j}}, \text{ in Pa} \quad (3c)$$

where

$P_{\text{ZO,j}}$ positive pressure at the flue gas inlet to the chimney segment j, in Pa

$P_{H,k}$ theoretical draught due to chimney effect in chimney segment k, in Pa
$P_{R,k}$ pressure resistance of the chimney segment k, in Pa
$P_{WOc,j}$ calculated positive differential pressure of the heating appliance j, in Pa
$P_{V,j}$ calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa
$P_{Bc,j}$ calculated pressure resistance of the air supply for the heating appliance j, in Pa
$P_{ZOe,j}$ maximum differential pressure at the flue gas inlet to the chimney segment j, in Pa
P_L wind velocity pressure,
N number of heating appliances

5.3 Mass flow requirement

Formulas (4) and/or (5) shall be verified for all relevant working conditions (see 5.6).

For each heating appliance in operation at nominal or minimum heat output:

$$\dot{m}_{Wc,j} \geq \dot{m}_{W,j} \text{, in kg/s} \quad (4)$$

and for each heating appliance out of action:

$$\dot{m}_{Wc,j} \geq 0 \text{, in kg/s} \quad (5)$$

where

$\dot{m}_{Wc,j}$ calculated mass flow of the heating appliance, in kg/s

$\dot{m}_{W,j}$ declared mass flow of the heating appliance, in kg/s

Where a damper is applied, flow resistance shall be taken as 0 unless additional data are available.

5.4 Pressure requirements

5.4.1 Negative pressure chimneys

For negative pressure chimneys it has to be additionally checked that the negative pressure (minimum draught) in the chimney ($P_{Z,j}$) is more than or equal to the negative pressure in the room where the heating appliance is placed at calculated draught conditions for air supply. The check on this pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

$$P_{Z,j} \geq P_{Bc,j} \text{, in Pa} \quad (6)$$

where

$P_{Z,j}$ draught at the inlet to the chimney segment j, in Pa

$P_{Bc,j}$ calculated pressure resistance of the air supply for the heating appliance j, in Pa

If required it has to be additionally checked that the negative pressure (draught) in the chimney ($P_{Zmax,j}$) is less than or equal to the maximum allowed draught ($P_{Zemax,j}$) caused by the heating appliance. The Formula (6a) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_L = 258,15 K (t_L = -15 °C, see EN 13384-1).

$$P_{\text{Zmax},j} = \sum_{k=j}^{N} \left(P_{\text{H,k}} - P_{\text{R,k}}\right) \leq P_{\text{Wmax,j}} + P_{\text{V,j}} + P_{\text{Bc,j}} = P_{\text{Zemax,j}} \text{, in Pa} \quad (6a)$$

where

$P_{\text{Zmax,j}}$	maximum draught at the flue gas inlet into the chimney segment j, in Pa
$P_{\text{Zemax,j}}$	maximum allowed draught at the flue gas inlet into the chimney segment j, in Pa
$P_{\text{H,k}}$	theoretical draught due to chimney effect in chimney segment k, in Pa
$P_{\text{R,k}}$	pressure resistance of the chimney segment k, in Pa
$P_{\text{Wmax,j}}$	maximum draught for the heating appliance j, in Pa
$P_{\text{V,j}}$	calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa
$P_{\text{Bc,j}}$	calculated pressure resistance of the air supply for the heating appliance j, in Pa

NOTE The values of $P_{\text{H,k}}$, $P_{\text{R,k}}$, $P_{\text{V,j}}$ and $P_{\text{Bc,j}}$ in Formulas (2) and (6a) are normally different because the conditions are different.

5.4.2 Positive pressure chimneys

For positive pressure chimneys it has to be additionally checked that the maximum positive pressure in the connecting flue pipe ($P_{\text{ZO,j}}$ + $P_{\text{V,j}}$) and in the chimney ($P_{\text{ZO,j}}$) is not higher than the excess pressure for which both are designated ($P_{\text{ZV excess}}$ and $P_{\text{Z excess}}$). The check on the pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

$$P_{\text{ZO,j}} \leq P_{\text{Z excess}} \text{, in Pa} \quad (6b)$$

$$P_{\text{ZO,j}} + P_{\text{V,j}} \leq P_{\text{ZV excess}} \text{, in Pa} \quad (6c)$$

where

$P_{\text{ZO,j}}$	positive pressure at the flue gas inlet to the chimney segment j, in Pa
$P_{\text{V,j}}$	calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa
$P_{\text{Z excess}}$	is the maximum allowed pressure from the designation of the chimney, in Pa
$P_{\text{ZV excess}}$	is the maximum allowed pressure from the designation of the connecting flue pipe, in Pa

If required it has to be additionally checked that the minimum positive pressure in the chimney ($P_{\text{ZOmin,j}}$) is more than or equal to the minimum allowed positive pressure ($P_{\text{ZOemin,j}}$) caused by the heating appliance. The relation (6d) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_{L} = 258,15 K (t_{L} = -15 °C, see EN 13384-1).

$$P_{\text{ZOmin,j}} = \sum_{k=j}^{N} \left(P_{\text{R,k}} - P_{\text{H,k}}\right) \geq P_{\text{WO min,j}} - P_{\text{Bc,j}} - P_{\text{V,j}} = P_{\text{ZOe min,j}} \text{, in Pa} \quad (6d)$$

where

$P_{\text{ZOmin,j}}$	minimum positive pressure at the flue gas inlet into the chimney segment j, in Pa

$P_{ZOemin,j}$ minimum differential pressure at the flue gas inlet into the chimney segment j, in Pa

$P_{H,k}$ theoretical draught due to chimney effect in chimney segment k, in Pa

$P_{R,k}$ pressure resistance of the chimney segment k, in Pa

$P_{WOmin,j}$ minimum differential pressure of the heating appliance j, in Pa

$P_{Bc,j}$ calculated pressure resistance of the air supply for the heating appliance j, in Pa

$P_{V,j}$ calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa

NOTE The values of $P_{H,k}$ and $P_{R,k}$ in Formulas (3b) and (6d) are normally different because the conditions are different.

5.5 Temperature requirement

The relation (7) shall be verified for all relevant working conditions (see 5.6).

The check of the temperature requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of $T_{uo,j}$ (see EN 13384-1)

$$T_{iob,j} \geq T_{g,j} \text{ , in K} \quad (7)$$

where

$T_{iob,j}$ temperature of the inner wall of the chimney segment j at the end, in K

$T_{g,j}$ temperature limit for chimney segment j, in K

The temperature limit $T_{g,j}$ for chimneys suitable for operating under dry conditions is equal to the condensing temperature $T_{sp,j}$ of the flue gas (see 8.6). $T_{g,j} = T_{sp,j}$

The temperature limit $T_{g,j}$ for chimneys suitable for operating under wet conditions is equal to the freezing point of water: $T_{g,j}$ = 273,15 K.

NOTE The following cases can be exempted from meeting the temperature requirement provided that it is accepted that in case the requirement for temperature should be not fulfilled no guarantee can be given that no moisture appears. In this cases insulation is advised.

— heating appliances which are substituted to a usual chimney which is already in operation and

— the heat output of the heating appliances which are connected and/or substituted does not exceed 30 kW for each and

— the flue gas losses are not more or equal than 8 % and

— an effective air conditioning of the chimney during standstill periods is given by draught diverters or dampers and

— sufficient standstill periods are given (e. g. the minimum steady state heat output of the heating appliance is not less than 20 % as the required heat).

5.6 Calculation procedure

For the calculation of the pressure and temperature values in a chimney serving more than one heating appliance an iterative procedure is necessary. This calculation procedure is based on the application of mass and energy conservation formulas under quasi steady state conditions.

In each point of connection between various ducts (at the end of connecting flue pipes, the beginning and the end of the chimney segments), all called nodes (see Figure 2), the following procedure shall be used:

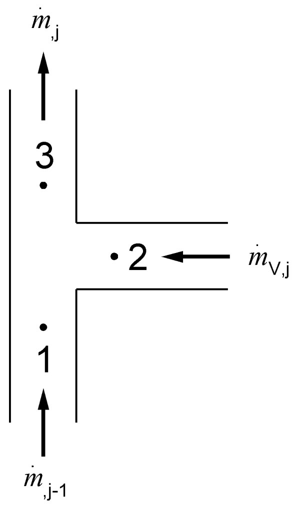


Figure 2 — Designation of flow numbering for each node *j* (see Formulas (8) and (9))

— The mass flow and the temperature shall be calculated with Formulas (8) and (9).

$$\dot{m}_{,j-1} + \dot{m}_{V,j} = \dot{m}_{,j} \text{, in kg/s} \tag{8}$$

$$\dot{m}_{,j-1} \cdot c_{p,j-1} \cdot T_{o,j-1} + \dot{m}_{V,j} \cdot c_{pV,j} \cdot T_{oV,j} = \dot{m}_{,j} \cdot c_{p,j} \cdot T_{e,j} \text{, in J/s} \tag{9}$$

where

$\dot{m}_{,j-1}$ flue gas mass flow in chimney segment j-1, in kg/s

$\dot{m}_{V,j}$ flue gas mass flow in connecting flue pipe, in kg/s

$\dot{m}_{,j}$ flue gas mass flow in chimney segment j, in kg/s

$c_{p,j-1}$ specific heat capacity of flue gas in chimney segment j-1, in J/(kg · K)

$c_{pV,j}$ specific heat capacity of flue gas in connecting flue pipe j, in J/(kg · K)

$c_{p,j}$ specific heat capacity of flue gas in chimney segment j, in J/(kg · K)

$T_{o,j-1}$ temperature of the flue gas at the end of chimney segment j-1, in K

$T_{oV,j}$ temperature of the flue gas at the end of connecting flue pipe j, in K

$T_{e,j}$ temperature of the flue gas at the inlet of chimney segment j, in K

— The draught or positive pressure at the beginning of the chimney segment (at point 3), is derived from the draught or positive pressure of this chimney segment and all succeeding segments according to Formula (2).

If the mass flow of a heating appliance doesn't change more than 10 % of its nominal value in a range between the nominal value and the calculated value for the draught or positive pressure an iteration is not necessary. In this case the requirements of EN 13384-1:2015, 5.2.1 or 5.2.2 shall be fulfilled for each appliance.

A CHP with combustion engine is assumed to fulfil these conditions.

For each iteration the following parameters shall be obtained:

— for each node j, the actual pressure ($P_{Ze,j}$, $P_{Z,j}$ or $P_{ZOe,j}$, $P_{ZO,j}$ and where required $P_{Zemax,j}$, $P_{Zmax,j}$ or $P_{ZOemin,j}$, $P_{ZOmin,j}$) and temperature values ($T_{o,j-1}$ at point 1, $T_{oV,j}$ at point 2, $T_{e,j}$ at point 3),

— for each segment between two nodes, the average values of the actual temperature, mass flow and velocity of the flue gas.

Before the first iteration an estimate of the calculated flue gas mass flow at the appliance outlet is necessary. A possible starting value for the calculated mass flow is the declared flue gas mass flow of the appliance $\dot{m}_{W,j}$.

Each iteration consists e.g. of the following two phases:

Phase 1: Calculate variables starting from the lowest node up to the outlet to the atmosphere as follows:

— calculated/estimated flue gas mass flow at the appliance outlet

— in each connecting flue pipe
calculated mass flow (Formula (14));
average density of the flue gas (Formula (29));
average velocity of the flue gas (Formula (30));
flue gas temperature at the end (see EN 13384-1:2015, 5.8);
average flue gas temperature (see EN 13384-1:2015, 5.8).

— in each segment of the chimney
calculated mass flow after the confluence of each segment (point 3 in Figure 2) (Formula (13));
temperature of the flue gas after the confluence (Formula (15))
average density of the flue gas (Formula (27));
average velocity of the flue gas (Formula (28));
flue gas temperature at the end (see EN 13384-1:2015, 5.8);
average flue gas temperature (see EN 13384-1:2015, 5.8).

Phase 2: Calculate the draught or positive pressure values in each node tracking the flue duct backwards from the outlet into the atmosphere down to the node that is at the greatest distance:

— draught required or differential pressure available at the flue gas inlet into the chimney (Formula (3) or (3c))

— draught due to chimney effect at the inlet of the chimney segment (Formula (31));

— pressure resistance in the chimney segment (using Formula (32));

— draught or positive pressure at the inlet of the chimney segment (using Formula (2) or (3b));

The iteration described above (phase 1 and phase 2) at the working conditions under consideration (i.e. nominal, minimum load and out of action) shall be continued until the pressure equilibrium condition is fulfilled (Formula (1)).

When the pressure equilibrium condition is fulfilled, the values calculated at the last iteration can be considered, for the purpose of this standard, to be those regarding the operation of the chimney.

If the pressure equilibrium condition is not fulfilled a new estimate of m_W based on the observed difference between $P_{Z,j}$ and $P_{Ze,j}$ or $P_{ZO,j}$ and $P_{ZOe,j}$ and a new iteration shall be made.

6 Flue gas data characterising the heating appliance

For the calculation of the temperature and pressure values the relevant flue gas data characterising the heating appliance shall be specified. This includes:

— minimum, declared draught or maximum declared differential pressure of the heating appliance ($P_{\mathrm{W,j}}$ or $P_{\mathrm{WO,j}}$)

— declared flue gas temperature of the heating appliance ($t_{\mathrm{W,j}}$)

Both values shall be given in relation to the flue gas mass flow at various working conditions of the heating appliances (in operation, out of action). The calculated draught $P_{\mathrm{Wc,j}}$ or differential pressure $P_{\mathrm{WOc,j}}$ of the heating appliance shall be given for both working conditions in form of a 4$^{\text{th}}$ degree poly-nominal (Formula (10)).

$$P_{\mathrm{Wc,j}} = b_{\mathrm{o}} + b_1 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right) + b_2 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^2 + b_3 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^3 + b_4 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^4 \text{ in Pa} \quad (10)$$

$$P_{\mathrm{WOc,j}} = c_{\mathrm{o}} + c_1 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right) + c_2 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^2 + c_3 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^3 + c_4 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^4 \text{ in Pa} \quad (10a)$$

$$t_{\mathrm{Wc,j}} = y_{\mathrm{o}} + y_1 \cdot \left(\frac{\dot{m}_{\mathrm{Wc,j}}}{\dot{m}_{\mathrm{W,j}}}\right)^{y_2}, \text{ in °C} \quad (11)$$

where

b_0, b_1, b_2, b_3, b_4	factors for the poly-nominal in the formula for calculated draught of heating appliance j
y_0, y_1, y_2	factors for the exponential in the formula for calculated flue gas temperature of heating appliance j
$\dot{m}_{\mathrm{Wc,j}}$	calculated flue gas mass flow of heating appliance j, in kg/s
$\dot{m}_{\mathrm{W,j}}$	declared flue gas mass flow of heating appliance j, in kg/s
$P_{\mathrm{Wc,j}}$	calculated draught of the heating appliance, in Pa
$P_{\mathrm{WOc,j}}$	calculated differential pressure of the heating appliance, in Pa
$t_{\mathrm{Wc,j}}$	calculated flue gas temperature of the heating appliance, in °C
c_0, c_1, c_2, c_3, c_4	factors for the poly-nominal in the formula for calculated differential pressure of heating appliance j

For negative pressure chimneys the values for b and y shall be obtained for “in operation” and “out of action” conditions separately. In case these values are not given, the flue gas data characterising the appliance are given in Annex B.

For positive pressure chimneys the values for c and y shall be obtained for the “in operation” conditions, from the heating appliance manufacture’s data.

NOTE 1 If the data for the “in operation” conditions are not available the calculation is not possible.

For the “out of action” condition c_0, c_1, c_3, c_4 and y_0, y_1, y_2 shall be 0 and c_2 = -1 000 000.

NOTE 2 For positive pressure applications the validation of the mass flow relies in the fact that there is no possibility of backflow of flue gas through a heating appliance that is out of action.

A CHP with combustion engine is sufficiently described with the nominal value for the flue gas mass flow and the nominal draught or differential pressure.

In addition the declared volumetric concentration of CO_2 of the flue gases at the relevant working conditions (nominal heat output and minimum heat output for the appliances $\sigma\cdot(CO_2)_{W,j}$ shall be specified. The declared content of CO_2 of the flue gases at the two working conditions can also be determined using EN 13384-1:2015, Table B.1 and Table B.2.

The calculated CO_2 content of the flue gas of the heating appliance j $\sigma(CO_2)_{Wtat,j}$ shall be determined for the two working conditions "in operation at nominal heat output" and "in operation at minimum output" using the following formula:

— for heating appliances for liquid and gaseous fuels and heating appliances for solid fuels with automatic feed

$$\sigma(CO_2)_{Wc,j} = \frac{1}{\left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}}\right)\frac{1}{\sigma(CO_2)_{W,j}} + \left[\left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}}\right) - 1\right]\frac{f_{m2}}{f_{m1}}} \text{, in Vol.-\%} \quad (12)$$

— in other cases

$\sigma(CO_2)_{Wc,j} = \sigma(CO_2)_{W,j}$, in Vol.-%

where

$\sigma(CO_2)_{W,j}$	declared CO_2 content of the flue gas of heating appliance j, in Vol.-%
$\sigma(CO_2)_{Wc,j}$	calculated CO_2 content of the flue gas of heating appliance j, in Vol.-%
f_{m1}, f_{m2}	coefficients according to EN 13384-1
$\dot{m}_{Wc,j}$	calculated flue gas mass flow of heating appliance j, in kg/s
$\dot{m}_{W,j}$	declared flue gas mass flow of heating appliance j, in kg/s

For the calculation of a negative pressure chimney the value of the maximum draught for the heating appliance P_{Wmax} and for the calculation of a positive pressure chimney the value of the minimum differential pressure of the heating appliance P_{WOmin} shall be obtained from the manufacturer of the heating appliance if appropriate.

7 Data for chimney and connecting flue pipes

The mean value for roughness of the inner wall (r_j and/or $r_{V,j}$) and the thermal resistance ($\left(\frac{1}{\Lambda}\right)_j$ and/or $\left(\frac{1}{\Lambda}\right)_{V,j}$) for each connecting flue pipe and each chimney segment shall be identified (see EN 13384-1:2015, 5.6.2).

8 Basic data for the calculation

8.1 General

The basic data for the calculation shall be identified for each chimney segment unless otherwise specified in this clause.

8.2 Air temperatures

8.2.1 External air temperature (T_L)

For the calculation of the external air temperature (T_L) see EN 13384-1:2015, 5.7.1.2; a single value is relevant for all chimney segments.

8.2.2 Ambient air temperature (T_u)

For the calculation of the ambient air temperature (T_u) see EN 13384-1:2015, 5.7.1.3.

8.3 External air pressure (p_L)

For the calculation of the external air pressure (p_L) see EN 13384-1:2015, 5.7.2, a single value is relevant for all chimney segments.

8.4 Gas constant

8.4.1 Gas constant of the air (R_L)

For the calculation of the gas constant of the air (R_L) see EN 13384-1:2015, 5.7.3.1, a single value is relevant for all chimney segments.

8.4.2 Gas constant of flue gas (R)

For the calculation of the gas constant of flue gas (R) see EN 13384-1:2015, 5.7.3.2.

For gas mixing use Formula (19) in this standard.

8.5 Density of air (ρ_L)

For the calculation of the density of air (ρ_L) see EN 13384-1:2015, 5.7.4. A single value is relevant for all chimney segments.

8.6 Specific heat capacity of the flue gas (c_p)

For the calculation of the specific heat capacity of the flue gas (c_p) see EN 13384-1:2015, 5.7.5.

For gas mixing use Formulas (20), (21), (22) in this standard.

8.7 Water vapour content ($\sigma(H_2O)_{,j}$) and condensing temperature (T_{sp})

For the calculation of the water vapour content ($\sigma(H_2O)_{,j}$) and condensing temperature (T_{sp}) see EN 13384-1:2015, 5.7.6.

For gas mixing use Formula (18) in this standard.

8.8 Correction factor for temperature instability (S_H)

A single value is relevant for all chimney segments.

For the check of the mass flow requirement and for the check of the pressure requirement for minimum draught and maximum positive pressure S_H = 0,5 shall be used for each chimney segment; for maximum draught or minimum positive pressure the correction factor S_H for temperature instability shall be 1.

8.9 Flow safety coefficient (S_E)

For the calculation of minimum draught of negative pressure chimneys the safety coefficient S_E = 1,5 shall be used, except a value of 1,2 shall be used for strictly controlled appliance and chimney installations (e.g. industrial installation with permanent supervision), and for room sealed appliances with forced draught burners.

For the calculation of maximum positive pressure of positive pressure chimneys the safety coefficient S_E = 1,2 shall be used.

For the air supply duct a flow safety coefficient S_{EB} = 1,2 shall be used.

For the calculation of maximum draught or minimum positive pressure the safety coefficient S_E and S_{EB} shall be 1.

8.10 External coefficient of heat transfer

For the calculation of the external coefficient of heat transfer see EN 13384-1:2015, 5.8.3.3.

9 Determination of temperatures

The following temperature values shall be calculated according to EN 13384-1:2015, 5.8

— the calculated flue gas temperatures of the heating appliance ($T_{wc,j}$) using flue gas data characterising the appliance (Formula (11));

— the mean flue gas temperatures in the connecting flue pipes ($T_{mV,j}$);

— the flue gas temperatures at the end of the connecting flue pipes ($T_{oV,j}$);

— the flue gas temperatures after gas mixing at the beginning of the chimney segments ($T_{e,j}$, Formula (7));

— the mean flue gas temperatures in the chimney segment ($T_{m,j}$);

— the flue gas temperatures at the end of the chimney segments ($T_{o,j}$); and

— the temperatures of the inner wall at the end of the chimney segments ($T_{iob,j}$).

The relevant formulas for the calculation of the temperatures are listed in Table 2. The mass flow rate and the CO_2 content of the flue gas in the connecting flue pipe shall be calculated with the Formulas (14) and (17).

Table 1 — Calculation of the temperatures

Terminology	Formula	Unit
mean flue gas temperature in connecting flue pipe $T_{mV,j}$	$T_{mV,j} = T_{uV,j} + \frac{T_{Wc,j} - T_{uV,j}}{K_{V,j}} \cdot \left[1 - \exp\left(- K_{V,j}\right)\right]$	K
flue gas temperature at the end of the connecting flue pipe T_{oV}	$T_{oV,j} = T_{uV,j} + (T_{Wc,j} - T_{uV,j}) \cdot \exp(- K_{V,j})$	K
cooling value of the connecting flue pipe $K_{V,j}$	$K_{V,j} = \frac{U_{V,j} \cdot k_{V,j} \cdot L_{V,j}}{m_{V,j} \cdot c_{pV,j}}$	–
coefficient of heat transmission of the connecting flue pipe $k_{V,j}$ (mass flow and pressure check)	$k_{V,j} = \left[\frac{1}{\alpha_{iV,j}} + S_H \cdot \left[\left(\frac{1}{\Lambda}\right)_{V,j} + \left(\frac{D_{hV,j}}{D_{hVa,j} \cdot \alpha_{aV,j}}\right)\right]\right]^{-1}$	$\frac{W}{m^2 \cdot K}$
coefficient of heat transmission of the connecting flue pipe $k_{V,j}$ (temperature check)	$k_{V,j} = \left[\frac{1}{\alpha_{iV,j}} + \left(\frac{1}{\Lambda}\right)_{V,j} + \left(\frac{D_{hV,j}}{D_{hVa,j} \cdot \alpha_{aV,j}}\right)\right]^{-1}$	$\frac{W}{m^2 \cdot K}$
internal coefficient of heat transfer of the connecting flue pipe $\alpha_{iV,j}$	$\alpha_{iV,j} = \max\left(\frac{\lambda_{AV,j} \cdot Nu_{V,j}}{D_{hV,j}} ;4\right)$	$\frac{W}{m^2 \cdot K}$
Nusselt number $Nu_{V,j}$	$Nv_{V,j} = \left[\frac{\psi}{\psi_{smooth}}\right]_{V,j}^{0,67} \cdot 0{,}0214 \cdot \left(Re_{V,j}^{0,8} - 100\right) \cdot Pr_{V,j}^{0,4} \cdot \left[1 + \left(\frac{D_{hV,j}}{L_{V,j}}\right)^{0,67}\right]$	–
Prandtl number $Pr_{V,j}$	$Pr_{V,j} = \frac{\eta_{AV,j} \cdot c_{pV,j}}{\lambda_{AV,j}}$	–
Reynolds number $Re_{V,j}$	$Re_{V,j} = \frac{w_{mV,j} \cdot D_{hV,j} \cdot \rho_{mV,j}}{\eta_{AV,j}}$	–
mean flue gas temperature $T_{m,j}$	$T_{m,j} = T_{u,j} + \frac{T_{e,j} - T_{u,j}}{K_{,j}} \cdot \left[1 - \exp\left(- K_{,j}\right)\right]$	K
flue gas temperature at the end of the chimney segment $T_{o,j}$	$T_{o,j} = T_{u,j} + \left(T_{e,j} - T_{u,j}\right) \cdot \exp\left(- K_{,j}\right)$	K
cooling value of the chimney segment $K_{,j}$	$K_{,j} = \frac{U_{,j} \cdot k_{,j} \cdot L_{,j}}{m_{,j} \cdot c_{p,j}}$	–
coefficient of heat transmission $k_{,j}$ (mass flow and pressure check)	$k_{,j} = \left[\frac{1}{\alpha_{i,j}} + S_H \cdot \left[\left(\frac{1}{\Lambda}\right)_{,j} + \left(\frac{D_{hi}}{D_{ha} \cdot \alpha_{a,j}}\right)\right]\right]^{-1}$	$\frac{W}{m^2 \cdot K}$

coefficient of heat transmission $k_{,j}$ (temperature check)	$k_{,j} = \left[\frac{1}{\alpha_{i,j}} + \left(\frac{1}{\Lambda}\right)_{,j} + \left(\frac{D_{hi}}{D_{ha} \cdot \alpha_{a,j}}\right) \right]^{-1}$	$\frac{W}{m^2 \cdot K}$
internal coefficient of heat transfer $\alpha_{i,j}$	$\alpha_{i,j} = \max\left(\frac{\lambda_{A,j} \cdot Nu_{,j}}{D_h}, 4\right)$	$\frac{W}{m^2 \cdot K}$
Nusselt number $Nu_{,j}$	$Nu_{,j} = \left[\frac{\psi}{\psi_{smooth}}\right]_{V,j}^{0,67} \cdot 0{,}0214 \cdot \left(Re_{,j}^{0,8} - 100\right) \cdot Pr_{,j}^{0,4} \cdot \left[1 + \left(\frac{D_{hV,j}}{L_{,j}}\right)^{0,67}\right]$	–
Prandtl number $Pr_{,j}$	$Pr_{,j} = \frac{\eta_{A,j} \cdot c_{p,j}}{\lambda_{A,j}}$	–
Reynolds number $Re_{,j}$	$Re_{,j} = \frac{w_{m,j} \cdot D_{h,j} \cdot \rho_{m,j}}{\eta_{A,j}}$	–

10 Mixing calculations

10.1 General

At the point of the inlet to the chimney segment the flue gas mass flow, the flue gas temperature and the CO_2 and H_2O-content as well as the gas constant and specific heat capacities shall be calculated.

10.2 Flue gas mass flow ($\dot{m}_{,j}$)

The flue gas mass flow in chimney segment j $\dot{m}_{,j}$ shall be calculated with Formulas (13) and (14):

$$\dot{m}_{,j} = \dot{m}_{,j-1} + \dot{m}_{V,j} \text{, in kg/s} \tag{13}$$

$$\dot{m}_{V,j} = \dot{m}_{Wc,j} \text{, in kg/s} \tag{14}$$

10.3 Flue gas temperature at the inlet of the chimney segment ($T_{e,j}$)

The flue gas temperature $T_{e,j}$ in chimney segment j shall be calculated with Formula (15). To simplify the calculation the heat capacities of the flue gas in the connecting flue pipe j and in the previous chimney segment j-1 are based on the mean flue gas temperatures.

$$T_{e,j} = \frac{\dot{m}_{,j-1} c_{p,j-1} T_{o,j-1} + \dot{m}_{V,j} c_{pV,j} T_{oV,j}}{\dot{m}_{j-1} c_{p,j-1} + \dot{m}_{V,j} c_{pV,j}} \text{, in K} \tag{15}$$

10.4 CO_2-content of the flue gas in the chimney segment ($\sigma(CO_2)_{,j}$)

The CO_2-content $\sigma(CO_2)_{,j}$ in chimney segment j shall be calculated with Formula (16):

$$\sigma(CO_2)_{,j} = \frac{\dot{m}_{j-1} R_{j-1} \left[100 - \sigma(H_2O)_{,j-1}\right] \sigma(CO_2)_{,j-1} + \dot{m}_{V,j} R_{V,j} \left[100 - \sigma(H_2O)_{V,j}\right] \sigma(CO_2)_{V,j}}{\dot{m}_{,j-1} R_{,j-1} \left[100 - \sigma(H_2O)_{,j-1}\right] + \dot{m}_{V,j} R_{V,j} \left[100 - \sigma(H_2O)_{V,j}\right]} \text{, in Vol. \%} \tag{16}$$

The CO_2-content of the flue gas in the connecting flue pipe shall be calculated with Formula (17):

$$\sigma(\text{CO}_2)_{\text{V,j}} = \sigma(\text{CO}_2)_{\text{Wc,j}}\text{, in Vol. \%} \tag{17}$$

10.5 H_2O-content of the flue gas ($\sigma(H_2O)_{,j}$)

The H_2O-content $\sigma(H_2O)_{,j}$ in chimney segment j shall be calculated with Formula (18):

$$\sigma(\text{H}_2\text{O})_{,\text{j}} = \frac{\dot{m}_{,\text{j-1}} R_{,\text{j-1}} \sigma(\text{H}_2\text{O})_{,\text{j-1}} + \dot{m}_{\text{V,j}} R_{\text{V,j}} \sigma(\text{H}_2\text{O})_{\text{V,j}}}{\dot{m}_{,\text{j-1}} R_{,\text{j-1}} + \dot{m}_{\text{V,j}} R_{\text{V,j}}}\text{, in Vol. \%} \tag{18}$$

$\sigma(H_2O)_{V,j}$ shall be taken from EN 13384-1:2015, Table B.1 for each kind of fuel for heating appliance j.

10.6 Gas constant of the flue gas ($R_{,j}$)

The gas constant of the flue gas $R_{,j}$ in chimney segment j shall be calculated with Formula (19):

$$R_{,\text{j}} = \frac{\dot{m}_{,\text{j-1}} R_{,\text{j-1}} + \dot{m}_{\text{V,j}} R_{\text{V,j}}}{\dot{m}_{,\text{j-1}} + \dot{m}_{\text{V,j}}}\text{, in J/(kg} \cdot \text{K)} \tag{19}$$

$R_{V,j}$ shall be taken from Table B.1 of EN 13384-1:2015 for each kind of fuel for heating appliance j.

10.7 Flue gas data

10.7.1 Specific heat capacity ($c_{pV,j}$), ($c_{p,j}$)

The specific heat capacity of the flue gas in the connecting flue pipe $c_{pV,j}$ shall be calculated with Formula (20):

$$c_{\text{pV,j}} = \frac{1011 + 0{,}05 \cdot t_{\text{mV,j}} + 0{,}0003 \cdot t_{\text{mV,j}}^2 + \left(f_{\text{cO,j}} + f_{\text{c1,j}} \cdot t_{\text{mV,j}} + f_{\text{c2,j}} \cdot t_{\text{mV,j}}^2\right)\sigma(\text{CO}_2)_{\text{V,j}}}{1 + \text{f}_{\text{c3,j}} \cdot \sigma(\text{CO}_2)_{\text{V,j}}}\text{, in J/(kg} \cdot \text{K)} \tag{20}$$

The factors $f_{c0,j}$, $f_{c1,j}$, $f_{c2,j}$ and $f_{c3,j}$ for determination of $c_{pV,j}$ shall be taken from EN 13384-1:2015, Table B.1

The specific heat capacity of the flue gas in the chimney segment $c_{p,j}$ shall be calculated with Formula (21):

$$c_{\text{p,j}} = \frac{1011 + 0{,}05 \cdot t_{\text{m,j}} + 0{,}0003 \cdot t_{\text{m,j}}^2 + \left(f_{\text{c0,j}} + f_{\text{c1,j}} \cdot t_{\text{m,j}} + f_{\text{c2,j}} \cdot t_{\text{m,j}}^2\right)\sigma(\text{CO}_2)_{,\text{j}}}{1 + f_{\text{c3,j}} \cdot \sigma(\text{CO}_2)_{,\text{j}}}\text{, in J/(kg} \cdot \text{K)} \tag{21}$$

The factors $f_{ci,j}$ for determination of $c_{p,j}$ shall be calculated with the following formula:

$$f_{\text{ci,j}} = \frac{1}{\sigma(\text{CO}_2)_{,\text{j}}} \cdot \frac{\dfrac{\dot{m}_{,\text{j-1}} \cdot f_{\text{ci,j-1}} \sigma(\text{CO}_2)_{,\text{j-1}}}{1 + f_{\text{c3,j-1}} \sigma(\text{CO}_2)_{,\text{j-1}}} + \dfrac{\dot{m}_{\text{V,j}} \cdot f_{\text{ciV,j}} \sigma(\text{CO}_2)_{\text{V,j}}}{1 + f_{\text{c3V,j}} \sigma(\text{CO}_2)_{\text{V,j}}}}{\dfrac{\dot{m}_{,\text{j-1}}}{1 + f_{\text{c3,j-1}} \sigma(\text{CO}_2)_{,\text{j-1}}} + \dfrac{\dot{m}_{\text{V,j}}}{1 + f_{\text{c3V,j}} \sigma(\text{CO}_2)_{\text{V,j}}}}\text{, in J/(kg} \cdot \text{K)} \tag{22}$$

When all appliances served by the chimney operate with the same fuel the coefficient $f_{ci,j}$ ($f_{c0,j}$, $f_{c1,j}$, $f_{c2,j}$ and $f_{c3,j}$) can be determined according to EN 13384-1:2015, Table B.1.

10.7.2 Thermal conductivity of the flue gas ($\lambda_{AV,j}$), ($\lambda_{A,j}$)

The thermal conductivity of the flue gas in the connecting flue pipe $\lambda_{AV,j}$ and/or in the chimney segment $\lambda_{A,j}$ shall be calculated with the following formulas:

$\lambda_{AV,j}$= 0,0223 + 0,000065 $t_{mV,j}$, in W/(m^2 · K) (23)

$\lambda_{A,j}$= 0,0223 + 0,000065 $t_{m,j}$, in W/(m^2 · K) (24)

10.7.3 Dynamic viscosity ($\eta_{AV,j}$), ($\eta_{A,j}$)

The dynamic viscosity $\eta_{AV,j}$ and $\eta_{A,j\ j}$ shall be calculated with the following formulas:

$$\eta_{AV,j} = 15 \cdot 10^{-6} + 47 \cdot 10^{-9} \cdot t_{mV,j} - 20 \cdot 10^{-12} \cdot t_{mV,j}^{2} \text{, in Ns/m}^2 \quad (25)$$

$$\eta_{A,j} = 15 \cdot 10^{-6} + 47 \cdot 10^{-9} \cdot t_{m,j} - 20 \cdot 10^{-12} \cdot t_{m,j}^{2} \text{, in Ns/m}^2 \quad (26)$$

Legend for the formulas in Clause 10

$c_{p,j}$	specific heat capacity of flue gas in chimney segment j, in J/(kg · K)
$c_{pV,j}$	specific heat capacity of flue gas in connecting flue pipe j, in J/(kg · K)
$f_{ci,j}$	factors for determination the specific heat capacity for each heating appliance j
$\dot{m}_{,j-1}$	flue gas mass flow in chimney segment j-1, in kg/s
$\dot{m}_{V,j}$	flue gas mass flow in connecting flue pipe j, in kg/s
R_{j-1}	specific gas constant of flue gas in chimney segment j, in J/(kg · K)
$R_{V,j}$	specific gas constant of flue gas in connecting flue pipe j, in J/(kg · K)
$t_{m,j}$	average temperature of flue gas in chimney segment j, in °C
$t_{mV,j}$	average temperature of flue gas in connecting flue pipe j, in °C
$t_{o,j-1}$	temperature of the flue gas at the end of chimney segment j-1, in K
$T_{oV,j-1}$	temperature of the flue gas at the end of connecting flue pipe j, in K
$\sigma(CO_2)_j$	volume concentration of CO_2 in chimney segment j, in Vol. %
$\sigma(CO_2)_{j-1}$	volume concentration of CO_2 in chimney segment j-1, in Vol. %
$\sigma(CO_2)_{V,j}$	volume concentration of CO_2 in connecting flue gas pipe j, in Vol. %
$\sigma(H_2O)_{j-1}$	volume concentration of H_2O in chimney segment j-1, in Vol. %
$\sigma(H_2O)_{V,j}$	volume concentration of H_2O in connecting flue gas pipe j, in Vol. %

10.7.4 Condensing temperature (T_{SP})

The condensing temperature shall be calculated according to EN 13384-1:2015, 5.7.6.

If there is a combination of appliances including such for coal and/or residual fuel oil the rise in the dew point shall be calculated for each fuel according to EN 13384-1:2015, 5.7.6 and the highest value shall be taken for the determination of the condensing temperature.

11 Density and velocity of the flue gas

The average density of the flue gas in the chimney segment $\rho_{m,j}$ shall be calculated with the following formula:

$$\rho_{m,j} = \frac{p_L}{R_{,j} \cdot T_{m,j}} \text{, in kg/m}^3 \quad (27)$$

The average velocity of the flue gas in the chimney segment $w_{m,j}$ shall be calculated with the following formula:

$$w_{m,j} = \frac{\dot{m}_{,j}}{A_{,j} \cdot \rho_{m,j}} \text{, in m/s} \quad (28)$$

The average density of the flue gas in the connecting flue pipe $\rho_{mV,j}$ shall be calculated with the following formula:

$$\rho_{mV,j} = \frac{p_L}{R_{V,j} \cdot T_{mV,j}} \text{, in kg/m}^3 \quad (29)$$

The average velocity of the flue gas in the connecting flue pipe $w_{Vm,j}$ shall be calculated with the following formula:

$$w_{mV,j} = \frac{\dot{m}_{V,j}}{A_{V,j} \cdot \rho_{mV,j}} \text{, in kg/m}^3 \quad (30)$$

Key to formulas in Clause 11

$A_{,j}$	cross sectional area of the chimney segment j, in m^2
$A_{V,j}$	cross sectional area of the connecting flue pipe j, in m^2
$\dot{m}_{,j}$	flue gas mass flow in the chimney segment j, in kg/s
$\dot{m}_{V,j}$	flue gas mass flow in the connecting flue pipe j, in kg/s
p_L	external air pressure, in Pa
$R_{,j}$	specific gas constant of the flue gas in chimney segment j, in J/(kg · K)
$R_{V,j}$	specific gas constant of the flue gas in connecting flue pipe j, in J/(kg · K)
$T_{m,j}$	average temperature of the flue gas in chimney segment j, in K
$T_{mV,j}$	average temperature of the flue gas in connecting flue pipe j, in K
$\rho_{m,j}$	average density of the flue gas in chimney segment j, in kg/m^3
$\rho_{mV,j}$	average density of flue gas in connecting flue pipe j, in kg/m^3

12 Determination of the pressures

12.1 Pressures at each inlet of the chimney segments

12.1.1 Draught

The minimum and maximum draught at the inlet of the chimney segment j ($P_{Z,j}$ and $P_{Zmax,j}$) results from the difference between the sum of draught due to chimney effect and the sum of the pressure resistance of all chimney segments which are located above the inlet and shall be calculated using Formulas (2) and (6a).

12.1.2 Positive pressure

The maximum and minimum positive pressure at the inlet of the chimney segment j ($P_{ZO,j}$ and $P_{ZOmin,j}$) results from the difference between the sum of the pressure resistance and the sum of draught due to chimney effect of all chimney segments which are located above the inlet and shall be calculated using Formulas (3b) and (6d).

12.1.3 Draught due to chimney effect in the chimney segment ($P_{H,j}$)

The draught due to chimney effect $P_{H,j}$ in chimney segment j shall be calculated with the following formula:

$$P_{H,j} = H_{,j} \cdot g \cdot (\rho_L - \rho_{m,j}), \text{ in Pa} \quad (31)$$

where

$H_{,j}$ effective height of chimney segment j, in m

g acceleration due to gravity = 9,81, m/s^2

ρ_L density of external air, in kg/m^3

$\rho_{m,j}$ average density of flue gas in section j, in kg/m^3

12.1.4 Pressure resistance in the chimney segment ($P_{R,j}$)

12.1.4.1 General

The pressure resistance $P_{R,j}$ in chimney segment j shall be calculated with the following formula:

$$P_{R,j} = S_E \left(\psi_{,j} \frac{L_{,j}}{D_h} + \sum \zeta_{,j} \right) \frac{\rho_{m,j}}{2} {w_{m,j}}^2 + S_{EM,j} P_{13,j} + S_{EG,j} P_{G,j} \text{, in Pa} \quad (32)$$

where

$P_{G,j}$ change of pressure due to change of flue gas velocity from chimney segment j to section j + 1, in Pa

$P_{13,j}$ change of pressure due to flue gas mixing in the area of the inlet in chimney segment j + 1, in Pa

S_E flow safety coefficient

$S_{EG,j}$ flow safety coefficient for change of pressure caused by change of velocity of the flue gas ($S_{EG,j} = S_E$ for $P_{G,j} \geq 0$; $S_{EG,j}$ = 1,0 for $P_{G,j} < 0$)

$S_{EM,j}$ flow safety coefficient for change of pressure caused by flow passing a connection ($S_{EM,j} = S_E$ for $P_{13,j} \geq 0$; $S_{EM,j}$ = 1,0 for $P_{13,j} < 0$)

$\psi_{,j}$ coefficient of friction of the flue of the chimney segment j

$L_{,j}$ length of chimney segment j, in m

$D_{h,j}$ internal hydraulic diameter of chimney segment j, in m

$\Sigma\zeta_{,j}$ sum of pressure resistance coefficients of the chimney segment j

$\rho_{m,j}$ average density of flue gas in chimney segment j, in kg/m^3

$w_{m,j}$ average velocity of flue gas in chimney segment j, in m/s

12.1.4.2 Coefficient of flow resistance due to friction of the flue (ψ)

For the calculation of the coefficient of friction of the flue of the chimney segment j ($\psi_{,j}$) see EN 13384-1:2015, 5.10.3.3. For the determination of the mean values for roughness of the inner wall (chimney segment and connecting flue pipe) see EN 13384-1:2015, Table B.4.

12.1.4.3 Pressure resistance coefficients

For the calculation of the pressure resistance coefficients see EN 13384-1:2015, Table B.7.

12.1.4.4 Pressure change in flue gas due to change of the flue gas velocity

For the calculation of the pressure change in flue gas due to change of the flue gas velocity see EN 13384-1:2015, 5.10.

The change of pressure $P_{G,j}$ from chimney segment j to j + 1 shall be calculated with the following formula:

$$P_{G,j} = \frac{\rho_{m,j+1}}{2} \cdot w_{m,j+1}^2 - \frac{\rho_{m,j}}{2} \cdot w_{m,j}^2 \text{ , in Pa} \tag{33}$$

where

$\rho_{m,j}$ average density of flue gas in chimney segment j, in kg/m^3

$w_{m,j}$ average velocity of flue gas in chimney segment j, in m/s

At the last chimney segment (the chimney outlet):

$P_{G,N} = 0$

12.1.4.5 Pressure loss due to mixing in the area of the inlet of the chimney segment (P_{13})

The pressure loss due to flue gas mixing at the inlet of the chimney segment $P_{13,j}$ (see Figure 3) is included in the pressure resistance of the chimney segment j below this inlet and it shall be calculated with the following formulas:

$$P_{13,j} = \zeta_{13,j+1} \cdot \frac{\rho_{m,j+1}}{2} \cdot w_{m,j+1}^2 \text{, in Pa} \tag{34}$$

$$\zeta_{13,j+1} = 0{,}03 \cdot \left(1 - \frac{\dot{m}_{V,j+1}}{\dot{m}_{,j+1}}\right)^2 - \left(\frac{\dot{m}_{V,j+1}}{\dot{m}_{,j+1}}\right)^2 \left[1 + 1{,}62 \cdot \left[\left(\frac{A}{A_{V,j+1}}\right) \cos \gamma_{,j} - 1\right] - 0{,}38 \cdot \left(1 - \left(\frac{A}{A_{V,j+1}}\right)^{-1}\right)\right] + \left[2 - \left(\frac{A}{A_{V,j+1}}\right)^{-1}\right] \cdot \frac{\dot{m}_{V,j+1}}{\dot{m}_{,j+1}} \cdot \left(1 - \frac{\dot{m}_{V,j+1}}{\dot{m}_{,j+1}}\right) \tag{35}$$

Formula (35) is only applicable if there is no change in chimney diameter

with $\frac{A}{A_{V,j+1}} \geq 1; \quad 0 \leq \frac{\dot{m}_{V,j+1}}{\dot{m}_{,j+1}} \leq 1{,}0; \quad 0° < \gamma \leq 90°$

For $\frac{A}{A_{V,j+1}} < 1$ the individual resistance of the connection point can be determined as sum of the individual resistances of a cross-section constriction (see EN 13384-1:2015, Table B.8, shape 6 and 8) and a connection point $\frac{A}{A_{V,j+1}} = 1$

where

A cross sectional area of the chimney, in m^2

$A_{V,j+1}$ cross sectional area of the connecting flue pipe j+1, in m^2

$\gamma_{,j+1}$	angle of the connection between the connecting flue pipe j+1 and the chimney segment j+1, in °
$\zeta_{13,j+1}$	pressure resistance coefficient of the connection between the connecting flue pipe j+1 and the chimney segment j+1
$\rho_{m,j+1}$	average density of the flue gas in chimney segment j+1, in kg/m^3
$w_{m,j+1}$	average velocity of the flue gas in chimney segment j+1, in m/s
$\dot{m}_{V,j+1}$	flue gas mass flow in connecting flue pipe j+1, in kg/s
$\dot{m}_{,j+1}$	flue gas mass flow in chimney segment j+1, in kg/s

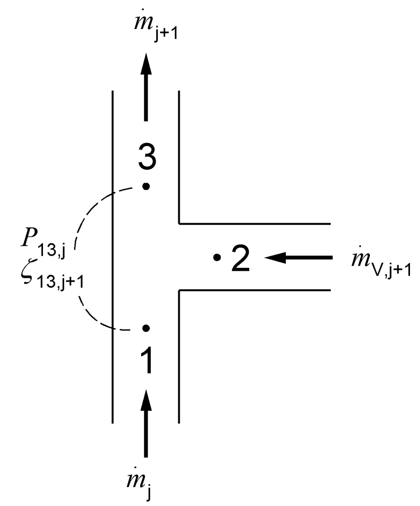


Figure 3 — Change of pressure due to flue gas mixing in the area of the inlet to chimney segment j+1

The pressure resistance coefficient values used in the calculation method presumes that there is no flow interference between individual points of connection of appliances.

This may be by adequate separation or by flow directions.

12.2 Minimum draught required at the flue gas inlet into the chimney and maximum allowed draught (P_{Ze} and P_{Zemax}) and maximum and minimum differential pressure at the flue gas inlet into the chimney (P_{ZOe} and P_{ZOemin})

12.2.1 Minimum required and maximum allowed draught

The minimum required draught $P_{Ze,j}$ at the outlet of the connecting flue pipe j is the sum of the calculated draught $P_{Wc,j}$ of heating appliance j and the calculated pressure resistance of the flue gas pipe $P_{V,j}$ and the calculated pressure resistance of the air supply $P_{Bc,j}$ and it shall be calculated using Formula (3).

The maximum allowed draught $P_{Zemax,j}$ at the outlet of the connecting flue pipe j is the sum of the calculated draught $P_{Wc,j}$ of heating appliance j and the calculated pressure resistance of the flue gas pipe $P_{V,j}$ and the calculated pressure resistance of the air supply $P_{Bc,j}$ and it shall be calculated using Formula (6a).

NOTE Values of $P_{Wc,j}$, $P_{V,j}$ and $P_{Bc,j}$ in Formulas (3) and (6a) may be different because the conditions are different.

12.2.2 Maximum available and minimum allowed differential pressure

The maximum differential pressure (available positive pressure) $P_{ZOe,j}$ at the outlet of the connecting flue pipe j is the difference of the calculated positive pressure differential $P_{WOc,j}$ of the heating appliance j and the sum of the calculated pressure resistance of the flue gas pipe $P_{V,j}$ and the calculated pressure resistance of the air supply $P_{Bc,j}$ and it shall be calculated using Formula (3c).

The minimum (allowed) differential pressure $P_{ZOemin,j}$ at the outlet of the connecting flue pipe j is the difference of the calculated positive pressure differential $P_{WOc,j}$ of the heating appliance j and the sum of the calculated pressure resistance of the flue gas pipe $P_{V,j}$ and the calculated pressure resistance of the air supply $P_{Bc,j}$ and it shall be calculated using Formula (6d).

NOTE The values of $P_{Wc,j}$, $P_{V,j}$ and $P_{Bc,j}$ in Formulas (3c) and (6d) may be different because the conditions are different.

12.2.3 Calculated pressure resistance of the connecting flue pipe ($P_{V,j}$)

12.2.3.1 General

The calculated pressure resistance of the connecting flue pipe $P_{V,j}$ shall be calculated with the following formula:

$$P_{V,j} = P_{RV,j} - P_{HV,j}' \text{ in Pa} \tag{36}$$

12.2.3.2 Draught due to chimney effect in the connecting flue pipe ($P_{HV,j}$)

For the calculation of the draught due to chimney effect in the connecting flue pipe ($P_{HV,j}$) see EN 13384-1:2015, 5.11.3.2.

12.2.3.3 Pressure resistance of the connecting flue pipe ($P_{RV,j}$)

The pressure resistance of the connecting flue pipe $P_{RV,j}$ shall be calculated with the following formula:

$$P_{RV,j} = S_E\left[\left(\psi_{V,j}\frac{L_{V,j}}{D_{hV,j}} + \sum\zeta_{V,j}\right)\frac{\rho_{mV,j}}{2}w_{mV,j}^2\right] + S_{EMV,j}P_{23,j} + S_{EGV,j}P_{GV,j}\text{, in Pa} \tag{37}$$

The pressure difference $P_{GV,j}$ is due to the difference between the velocity of flue gas in the connecting flue pipe and in the corresponding chimney segment j. It shall be calculated with the following formula:

$$P_{GV,j} = \frac{\rho_{m,j}}{2}\cdot w_{m,j}^2 - \frac{\rho_{mV,j}}{2}\cdot w_{mV,j}^2\text{, in Pa} \tag{38}$$

where

S_E	flow safety coefficient
$S_{EGV,j}$	flow safety coefficient for change of pressure caused by change of velocity of the flue gas $S_{EGV,j} = S_E$ for $P_{GV,j} \geq 0$; $S_{EGV,j} = 1{,}0$ for $P_{GV,j} < 0$
$S_{EMV,j}$	flow safety coefficient for $P_{23,j}$ ($S_{EMV,j} = S_E$ for $P_{23,j} \geq 0$; $S_{EMV,j} = 1{,}0$ for $P_{23,j} < 0$)
$\psi_{V,j}$	coefficient of friction of the flue gas pipe j
$L_{V,j}$	length of the connecting flue gas pipe j, in m
$D_{hV,j}$	internal hydraulic diameter of flue gas pipe, in m
$\Sigma\zeta_{V,j}$	sum of resistance coefficients of the connecting flue pipe (exclusive of the mixing effects at the inlet to the chimney)
$\rho_{mV,j}$	average density of the connecting flue gas in the flue gas pipe, in kg/m^3
$w_{mV,j}$	average velocity of the connecting flue gas in the flue gas pipe, in m/s

The pressure loss $P_{23,j}$ (see Figure 4) is due to the change of flow direction and mixing of flue gas in the area of the inlet into chimney segment j. It shall be calculated with the following formulas:

$$P_{23,j} = \zeta_{23,j} \cdot \frac{\rho_{m,j}}{2} \cdot w_{m,j}^2 \text{, in Pa} \tag{39}$$

$$\zeta_{23,j} = -0{,}92 \cdot \left(1 - \frac{\dot{m}_{V,j}}{\dot{m}_{,j}}\right)^2 - \left(\frac{\dot{m}_{V,j}}{\dot{m}_{,j}}\right)^2 \cdot \left[1{,}2 \cdot \left(\frac{A}{A_{V,j}} \cos\gamma_{,j} - 1\right) + 0{,}8 \cdot \left(1 - \left(\frac{A}{A_{V,j}}\right)^2\right) - \left(1 - \left(\frac{A}{A_{V,j}}\right)^{-1}\right) \cdot \frac{A}{A_{V,j}} \cdot \cos\gamma_{,j}\right] + \left(2 - \left(\frac{A}{A_{V,j}}\right)^{-1}\right) \cdot \frac{\dot{m}_{V,j}}{\dot{m}_{,j}} \cdot \left(1 - \frac{\dot{m}_{V,j}}{\dot{m}_{,j}}\right) \tag{40}$$

with $\frac{A}{A_{V,j}} \geq 1; 0 \leq \frac{\dot{m}_{V,j}}{\dot{m}_{,j}} \leq 1{,}0; 0° < \gamma \leq 90°$

For $\frac{A}{A_{V,j}} < 1$ the individual resistance of the connection point can be determined as sum of the individual resistances of a cross-section constriction (see EN 13384-1:2015, Table B.8, shape 6 and 8) and a connection point $\frac{A}{A_{V,j}} = 1$

where

- $\zeta_{23,j}$ pressure resistance coefficient for change in flue gas direction and mixing at the area of flue gas inlet j in chimney segment j
- $\rho_{m,j}$ average density of the flue gas in chimney segment j, in kg/m^3
- $w_{m,j}$ average flue gas velocity in chimney segment j, in m/s
- $\dot{m}_{V,j}$ flue gas mass flow in connecting flue gas pipe j, in kg/s
- $\dot{m}_{,j}$ flue gas mass flow in chimney segment j, in kg/s
- $A_{V,j}$ cross sectional area of connecting flue pipe j, in m^2
- A cross sectional area of chimney, in m^2
- $\gamma_{,j}$ angle of connection between connecting flue pipe and the chimney segment, in °

The pressure resistance coefficient values used in the calculation method presumes that there is no flow interference between individual points of connection of appliances.

This may be achieved by adequate separation of points of connection or by the use of flow deflectors.

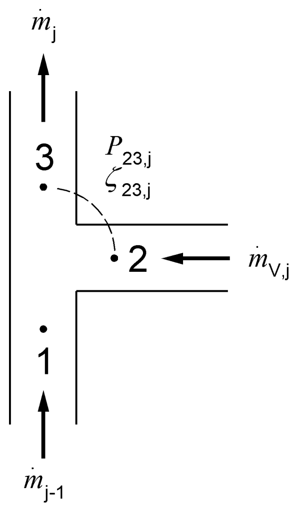


Figure 4 — Pressure loss P_{23j} due to the change of flow direction and mixing of flue gas in the area of the inlet into chimney segment j

12.2.3.4 Coefficient of flow resistance (ζ)

For the calculation of the coefficient of flow resistance (ζ) see EN 13384-1:2015, 5.10.3.4.

Values for devices which positively isolate the heating appliance to prevent flue gas back flow shall be supplied by the device manufacturer.

12.2.4 Calculated pressure resistance of the air supply ($P_{Bc,j}$)

The pressure resistance of the air supply ($P_{B,j}$) shall be calculated in accordance to EN 13384-1:2015, 5.11.4.

The calculated (negative) pressure resistance for air supply $P_{Bc,j}$ is calculated with the following formula:

$$P_{Bc,j} = P_{B,j} \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right)^n \text{, in Pa} \qquad (41)$$

where

$P_{B,j}$ minimum, projected pressure resistance of air supply for the heating appliance j, in Pa

$\dot{m}_{Wc,j}$ calculated flue gas mass flow for heating appliance j, in g/s

$\dot{m}_{W,j}$ declared flue gas mass flow of heating appliance j, in g/s

n exponent depending on the kind of air supply:

- in case of an opening (e.g. room for the heating appliance with an opening for air supply): n = 2
- in case of slits (e.g. window frame in living rooms): n = 1,5

In case more than one heating appliance in a room is connected to the inlet of the chimney segment the sum of the flue gas mass flows shall be used in Formula (41) for $\dot{m}_{Wc,j}$ and $\dot{m}_{W,j}$.

13 Inner wall temperature

The temperature of the inner wall of the chimney $T_{iob,j}$ of a chimney segment j shall be calculated in analogy to EN 13384-1:2015, 5.12 using formulas in Table 2.

Table 2 — Formulas for calculation of inner wall temperatures at the end of a chimney segment

Terminology	Formula	Unit
coefficient of heat transmission at the end of the chimney segment $k_{ob,j}$	$k_{ob,j} = \left(\frac{1}{\alpha_{i,j}} + \left(\frac{1}{\Lambda}\right)_{,j} + \left(\frac{1}{\Lambda}\right)_{o,j} + \frac{D_h}{D_{hao,j} \cdot \alpha_{ao,j}} \right)^{-1}$	$\frac{W}{m^2 \cdot K}$
flue gas temperature at the inner wall $T_{iob,j}$	$T_{iob,j} = T_{ob,j} - \frac{k_{ob,j}}{\alpha_{i,j}} \cdot \left(T_{ob,j} - T_{uo,j}\right)$ with $T_{uo,j}$ see Table 2	K
section j < N	$\alpha_{ao,j} = 23$ in the case any part of the chimney segment is external $\alpha_{ao,j} = 8$ in the case where the chimney segment is internal to the building $(1/\Lambda)_{o,j} = 0$ in the case where the entire chimney segment is not insulated	$\frac{W}{m^2 \cdot K}$
section j = N	In the case of ventilated cladding with ventilated gaps of a width of 1 cm to 5 cm $\alpha_{ao} = 8$ may be used. $\alpha_{ao,j} = 23$ in all other cases of a non-insulated top of the chimney or when an additional heat transfer resistance of an insulated top of a chimney is included in the calculations $(1/\Lambda)_{o,j}$ = calculated according to EN 13384-1:2015, A.1	$\frac{W}{m^2 \cdot K}$

14 Cascade installations

14.1 Principle of the calculation method

The calculation is based upon determining the mass flow distribution in the collectors (see Figure 5) which fulfils the pressure equilibrium condition (Formula (42)) at each flue gas inlet to each collector segment. After such a distribution has been found three requirements shall be verified:

a) the mass flow requirement (Formulas (45) and (46))

b) the pressure requirement for minimum draught or maximum positive pressure (Formulas (47) or (47b) and (47c))

c) the pressure requirement for maximum draught or minimum positive pressure (Formulas (47a) or (47d))

d) the temperature requirement (Formula (48))

The inlet/outlet construction is assumed to be designed in such a way that wind effects are minimized. Consequently P_L = 0 and is omitted from the formulas.

14.2 Pressure equilibrium condition

14.2.1 Negative pressure cascade installation

The following formulas shall be fulfilled for each collector segment j,l at all relevant working conditions:

$$\left|P_{\text{ZC,j,l}} - P_{\text{ZeC,j,l}}\right| \leq 0{,}1 \text{, in Pa} \tag{42}$$

$$P_{\text{ZC,j,l}} = P_{\text{Z,j}} + \sum_{\text{n}=l}^{NCj} \left(P_{\text{HC,j,n}} - P_{\text{RC,j,n}}\right) \text{, in Pa} \tag{43}$$

$$P_{\text{ZeC,j,l}} = P_{\text{Wc,j,l}} + P_{\text{V,j,l}} + P_{\text{Bc,j,l}} \text{, in Pa} \tag{44}$$

where

$P_{\text{ZC,j,l}}$ draught at the flue gas inlet into the collector segment j,l, in Pa

$P_{\text{HC,j,n}}$ theoretical draught due to chimney effect in collector segment j,n, in Pa

$P_{\text{RC,j,n}}$ pressure resistance of the collector segment j,n, in Pa

$P_{\text{Wc,j,l}}$ calculated draught of the heating appliance j,l, in Pa

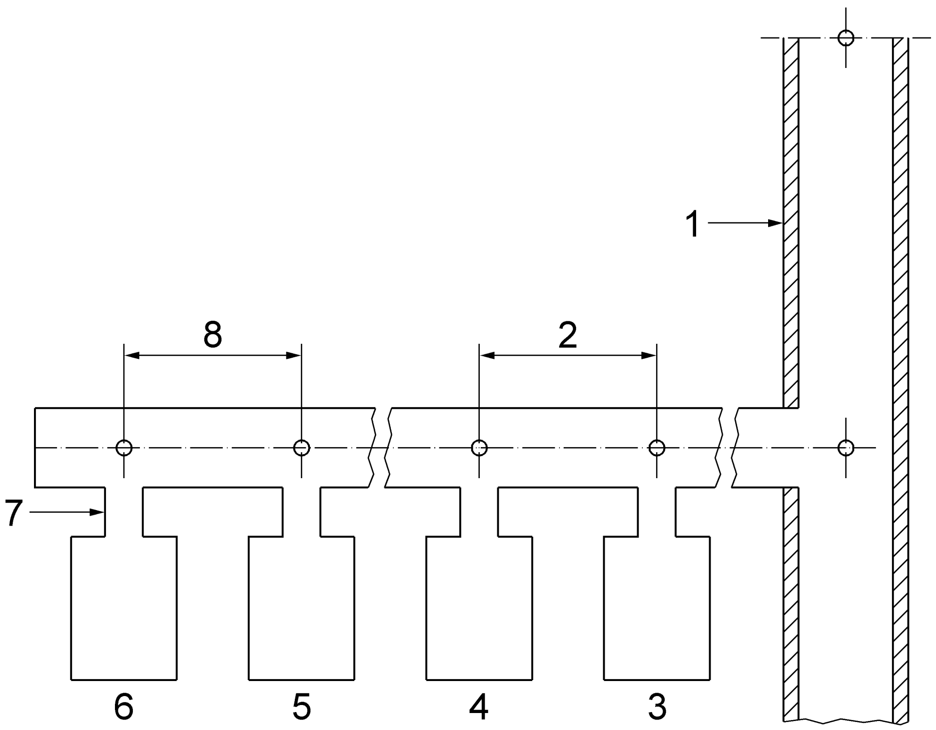
$P_{\text{V,j,l}}$ calculated pressure resistance of the connecting flue pipe of the heating appliance j,l, in Pa

$P_{\text{Bc,j,l}}$ calculated pressure resistance of the air supply for the heating appliance j,l, in Pa

$P_{\text{ZeC,j,l}}$ required draught at the flue gas inlet into the collector segment j,l, in Pa

$P_{\text{Z,j}}$ draught at the flue gas inlet to the chimney segment j, in Pa

$NC_{,\text{j}}$ number of heating appliances of the collector j



Key

1 chimney
2 collector segment j,l
3 heating appliance j,l + 1
4 heating appliance j,p
5 heating appliance j;2
6 heating appliance j,1
7 connecting flue pipe
8 collector segment j,1

Figure 5 — Example of cascade arrangement and numbering of heating appliances and collector segments

14.2.2 Positive pressure cascade installation

The following formulas shall be fulfilled for each collector segment j, l at all relevant working conditions:

$$\left| P_{\text{ZOeC,j,l}} - P_{\text{ZOC,j,l}} \right| \leq 0{,}1 \text{, in Pa} \qquad (44a)$$

$$P_{\text{ZOC,j,l}} = P_{\text{ZO,j}} + \sum_{n=l}^{NCj} \left(P_{\text{RC,j,n}} - P_{\text{HC,j,n}} \right) \text{, in Pa} \qquad (44b)$$

$$P_{\text{ZOeC,j,l}} = P_{\text{WOc,j,l}} - P_{\text{V,j,l}} - P_{\text{Bc,j,l}} \text{, in Pa} \qquad (44c)$$

where

$P_{\text{ZOC,j,l}}$ positive pressure at the flue gas inlet into the collector segment j, l, in Pa

$P_{\text{HC,j,n}}$ theoretical draught due to chimney effect in collector segment j, n, in Pa

$P_{RC,j,n}$ pressure resistance of the collector segment j, n, in Pa

$P_{WOc,j,l}$ calculated positive differential pressure of the heating appliance j, l, in Pa

$P_{V,j,l}$ calculated pressure resistance of the connecting flue pipe of the heating appliance j, l, in Pa

$P_{Bc,j,l}$ calculated pressure resistance of the air supply for the heating appliance j, l, in Pa

$P_{ZOeC,j,l}$ maximum differential pressure at the flue gas inlet into the collector segment j, l, in Pa

$P_{ZO,j}$ positive pressure at the inlet of the chimney segment j, in Pa

NC_j number of heating appliances of the collector j

14.3 Mass flow requirement

Formulas (45) and/or (46) shall be verified for all relevant working conditions (see 5.6).

For each heating appliance in operation at nominal or minimum heat output:

$$\dot{m}_{Wc,j,l} \geq \dot{m}_{W,j,l} \text{, in kg/s} \tag{45}$$

and for each heating appliance out of action:

$$\dot{m}_{Wc,j,l} \geq 0 \text{, in kg/s} \tag{46}$$

where

$\dot{m}_{Wc,j,l}$ calculated mass flow of the heating appliance j,l, in kg/s

$\dot{m}_{W,j,l}$ declared mass flow of the heating appliance j,l, in kg/s

Where a damper is applied, flow resistance shall be taken as 0 unless additional data are available.

14.4 Pressure requirements

14.4.1 Negative pressure chimneys

For negative pressure cascade installations it has to be additionally checked that the negative pressure (draught) in the collector ($P_{ZC,j,l}$) is more than or equal to the negative pressure in the room where the heating appliance is placed at calculated draught conditions for air supply. The check on the pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 14.3 and 14.6). The following relations shall be verified:

$$P_{ZC,j,l} \geq P_{Bc,j,l} \text{, in Pa} \tag{47}$$

where

$P_{ZC,j,l}$ draught at the inlet into the collector segment j,l, in Pa

$P_{Bc,j,l}$ calculated pressure resistance of the air supply for the heating appliance j,l, (see 12.2.4), in Pa

If required it has to be additionally checked that the negative pressure (draught) in the collector ($P_{ZCmax,j,l}$) is less than or equal to the maximum allowed draught ($P_{ZeCmax,j,l}$) caused by the heating appliance. The relation (47a) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_L = 258,15 K (t_L = -15 °C, see EN 13384-1).

$$P_{\text{ZCmax,j,l}} = P_{\text{Z,j}} + \sum_{\text{n}=l}^{NCj} \left(P_{\text{HC,j,n}} - P_{\text{RC,j,n}}\right) \leq \text{P}_{\text{Wmax,j,l}} + P_{\text{V,j,l}} + P_{\text{Bc,j,l}} = P_{\text{ZeCmax,j,l}} \text{ in Pa} \quad (47a)$$

where

$P_{\text{ZCmax,j,l}}$	maximum draught at the flue gas inlet into the collector segment j,l, in Pa
$P_{\text{Z,j}}$	draught at the flue gas inlet to the chimney segment j, in Pa
$P_{\text{HC,j,n}}$	theoretical draught due to chimney effect in collector segment j,n, in Pa
$P_{\text{RC,j,n}}$	pressure resistance of the collector segment j,n, in Pa
$P_{\text{Wmax,j,l}}$	maximum draught of the heating appliance j, l, in Pa
$P_{\text{V,j,l}}$	calculated pressure resistance of the connecting flue pipe of the heating appliance j, l, in Pa
$P_{\text{Bc,j,l}}$	calculated pressure resistance of the air supply for the heating appliance j,l (see 12.2.4), in Pa
$P_{\text{ZeCmax,j,l}}$	maximum allowed draught at the flue gas inlet into the collector segment j, l, in Pa
$NC_{\text{,j}}$	number of heating appliances of the collector j

NOTE The values of $P_{\text{HC,j,n}}$ and $P_{\text{RC,j,n}}$ in Formulas (43) and (47a) are normally different because the conditions are different.

14.4.2 Positive pressure chimneys

For positive pressure cascade installations it has to be additionally checked that the maximum positive pressure in the connecting flue pipe and in the collector is not higher than the excess pressure for which both are designated. The check on the pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 14.3 and 14.6). The following relations shall be verified:

$$P_{\text{ZOC,j}} \leq P_{\text{ZC excess,}} \text{ in Pa} \quad (47b)$$

$$P_{\text{ZOC,j}} + P_{\text{V,j,l}} \leq P_{\text{ZV excess}}, \text{ in Pa} \quad (47c)$$

where

$P_{\text{ZOC,j}}$	positive pressure at the flue gas inlet to the chimney segment j, in Pa
$P_{\text{V,j,l}}$	calculated pressure resistance of the connecting flue pipe of collector segment j,l, in Pa
$P_{\text{ZC excess}}$	is the maximum allowed pressure from the designation of the collector, in Pa
$P_{\text{ZV excess}}$	is the maximum allowed pressure from the designation of the connecting flue pipe, in Pa

If required it has to be additionally checked that the positive pressure in the collector ($P_{\text{ZOCmin,j,l}}$) is more than or equal to the minimum allowed positive pressure ($P_{\text{ZOCe min,j,l}}$) caused by the heating appliance. The relation (47d) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_L = 258,15 K (t_L = -15 °C, see EN 13384-1).

$$P_{\text{ZOCmin,j,l}} = P_{\text{ZO,j}} + \sum_{\text{n}=l}^{NCj} \left(P_{\text{RC,j,n}} - P_{\text{HC,j,n}}\right) \geq P_{\text{WO min,j,l}} - P_{\text{Bc,j,l}} - P_{\text{V,j,l}} = P_{\text{ZOCe min,j,l}} \text{, in Pa} \quad (47d)$$

where

$P_{\text{ZOCmin,j,l}}$ minimum positive pressure at the flue gas inlet into the collector segment j,l, in Pa

$P_{\text{ZOCemin,j,l}}$ minimum differential pressure at the flue gas inlet into the collector segment j,l, in Pa

$P_{\text{HC,j,n}}$ theoretical draught due to chimney effect in collector segment j,n, in Pa

$P_{\text{RC,j,n}}$ pressure resistance of the collector segment j,n, in Pa

$P_{\text{WOmin,j,l}}$ minimum differential pressure of the heating appliance j,l, in Pa

$P_{\text{Bc,j,l}}$ calculated pressure resistance of the air supply for the heating appliance j,l, in Pa

$P_{\text{V,j,l}}$ calculated pressure resistance of the connecting flue pipe of collector segment j,l, in Pa

NOTE The values of $P_{\text{HC,j,n}}$ and $P_{\text{RC,j,n}}$ in Formulas (44b) and (47d) are normally different because the conditions are different.

14.5 Temperature requirement

The relations 48 shall be verified for all relevant working conditions (see 5.6).

The check of the temperature requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of $T_{\text{L}} = T_{\text{uo}}$.

$$T_{\text{iob,j,l}} \geq T_{\text{g,j,l}} \text{, in K} \quad (48)$$

where

$T_{\text{iob,j,l}}$ temperature of the inner wall of the collector segment j,l at the end, in K

$T_{\text{g,j,l}}$ temperature limit for collector segment j,l, in K

The temperature limit $T_{\text{g,j,l}}$ suitable for operating under dry conditions is equal to the condensing temperature $T_{\text{sp,j,l}}$ of the flue gas (see 8.6): $T_{\text{g,j,l}} = T_{\text{sp,j,l}}$

The temperature limit $T_{\text{g,j,l}}$ suitable for operating under wet conditions is equal to the freezing point of water: $T_{\text{g,j,l}}$ = 273,15 K.

14.6 Calculation procedure

For the calculation procedure see 5.6.

14.7 Pressures at the outlet of the connecting flue pipe and pressures at the inlet of the collector segment

14.7.1 Pressure at the flue gas inlet into the collector segment ($P_{\text{ZC,j,l}}$ or $P_{\text{ZOC,j,l}}$)

14.7.1.1 Draught

The minimum and maximum draught at the inlet of the collector segment j,l ($P_{\text{ZC,j,l}}$ and $P_{\text{ZCmax,j,l}}$) shall be calculated using Formulas (43) and (47a).

14.7.1.2 Positive pressure

The maximum and minimum differential pressure at the inlet of the collector segment j,l ($P_{ZOC,j,l}$ and $P_{ZOCmin,j,l}$) shall be calculated using Formulas (44b) and (47d).

14.7.1.3 Draught due to chimney effect in the collector segment ($P_{HC,j,l}$)

The draught due to chimney effect $P_{HC,j,l}$ in collector segment j,l shall be calculated with the following formula:

$$P_{HC,j,l} = H_{C,j,l} \cdot g \cdot (\rho_L - \rho_{mC,j,l}), \text{ in Pa} \tag{49}$$

where

$H_{C,j,l}$ effective height of collector segment j,l, in m

g acceleration due to gravity = 9,81, in m/s^2

ρ_L density of external air, in kg/m^3

$\rho_{mC,j,l}$ average density of flue gas in section j,l, in kg/m^3

14.7.1.4 Pressure resistance in the collector segment ($P_{RC,j,l}$)

14.7.1.4.1 General

The pressure resistance $P_{RC,j,l}$ in collector segment j,l shall be calculated with the following formula:

$$P_{RC,j,l} = S_E \left(\psi_{C,j,l} \frac{L_{C,j,l}}{D_{hC,j,l}} + \sum \zeta_{C,j,l} \right) \frac{\rho_{mC,j,l}}{2} w_{mC,j,l}^2 + S_{EMC,j,l} P_{13C,j,l} + S_{EGC,j,l} P_{GC,j,l} \text{ , in Pa} \tag{50}$$

where

$P_{GC,j,l}$ change of pressure due to change of flue gas velocity from collector segment j,l to section j,l+1, in Pa

$P_{13C,j,l}$ pressure loss due to mixing of flue gas in the area of the inlet into collector segment j,l+1, in Pa

S_E flow safety coefficient

$S_{EGC,j,l}$ flow safety coefficient for change of pressure caused by change of velocity of the flue gas
($S_{EGC,j,l} = S_E$ for $P_{GC,j,l} \geq 0$; $S_{EGC,j,l} = 1{,}0$ for $P_{GC,j,l} < 0$)

$S_{EMC,j,l}$ flow safety coefficient for change of pressure caused by flow passing a connection
($S_{EMC,j,l} = S_E$ for $P_{13C,j,l} \geq 0$; $S_{EMC,j,l} = 1{,}0$ for $P_{13C,j,l} < 0$)

$\psi_{C,j,l}$ coefficient of friction of the flue of the collector segment i,l

$L_{C,j,l}$ length of the collector segment j,l, in m

$D_{hC,j,l}$ internal hydraulic diameter of the collector segment j,l, in m

$\Sigma\zeta_{C,j,l}$ sum of pressure resistance coefficients of the collector segment j,l

$\rho_{mC,j,l}$ average density of flue gas in collector segment j,l, in kg/m^3

$w_{mC,j,l}$ average velocity of flue gas in collector segment j,l, in m/s

At the last collector segment j,NCj (to the chimney inlet) put $P_{23,j}$ instead $P_{13C,j,NCj}$

where

$P_{23,j}$ pressure loss due to the change of flue direction and mixing of the flue gas in the area of the inlet into chimney segment j, in Pa

14.7.1.4.2 Coefficient of flow resistance due to friction of the flue (ψ)

For the calculation of the coefficient of friction of the flue of the collector segment j ($\psi_{C,j}$) see EN 13384-1:2015, 5.10.3.3. For the determination of the mean value for roughness of the inner wall (collector segment and connecting flue pipe) see EN 13384-1:2015, Table B.4.

14.7.1.4.3 Pressure resistance coefficients

For the calculation of the pressure resistance coefficients see EN 13384-1:2015, Table B.7.

14.7.1.4.4 Pressure change in flue gas due to change of the flue gas velocity ($P_{GC,j,l}$)

For the calculation of the pressure change in flue gas due to change of the flue gas velocity ($P_{GC,j,l}$) see EN 13384-1:2015, 5.10.3.2.

The change of pressure $P_{G,j}$ from collector segment j,l to j,l+1 shall be calculated with the following formula:

$$P_{GC,j,l} = \frac{\rho_{mC,j,l+1}}{2} \cdot w_{mC,j,l+1}^2 - \frac{\rho_{mC,j,l}}{2} \cdot w_{mC,j,l}^2 \text{, in Pa} \tag{51}$$

At the last collector segment j,NCj (to the chimney inlet):

$$P_{GC,j,NCj} = \frac{\rho_{m,j}}{2} \cdot w_{m,j}^2 - \frac{\rho_{mC,j,NCj}}{2} \cdot w_{mC,j,NCj}^2 \text{, in Pa} \tag{52}$$

where

$\rho_{mC,j,l}$ average density of flue gas in collector segment j,l, in kg/m^3

$w_{mC,j,l}$ average velocity of flue gas in collector segment j,l, in m/s

$\rho_{m,j}$ average density of flue gas in chimney segment j, in kg/m^3

$w_{m,j}$ average velocity of flue gas in chimney segment j, in m/s

14.7.1.4.5 Pressure loss due to mixing of flue gas in the area of the inlet of the collector segment ($P_{13C,j,l}$)

The pressure loss due to flue gas mixing at the inlet of the collector segment $P_{13,j,l}$ is included in the pressure resistance of the collector segment before this inlet and it shall be calculated with the following formulas:

$$P_{13C,j,l} = \zeta_{13C,j,l+1} \cdot \frac{\rho_{mC,j,l+1}}{2} \cdot w_{mC,j,l+1}^2 \text{, in Pa} \tag{53}$$

$$\zeta_{13C,j,l+1} = 0{,}03 \cdot \left(1 - \frac{\dot{m}_{V,j,l+1}}{\dot{m}_{C,j,l+1}}\right)^2 - \left(\frac{\dot{m}_{V,j,l+1}}{\dot{m}_{C,j,l+1}}\right)^2 \cdot \left\{1 + 1{,}62 \cdot \left(\frac{A_{C,j,l+1}}{A_{V,j,l+1}} \cos \gamma_{C,j,l+1} - 1\right) - 0{,}38 \cdot \left[1 - \left(\frac{A_{C,j,l+1}}{A_{V,j,l+1}}\right)^{-1}\right]\right\} + \left[2 - \left(\frac{A_{C,j,l+1}}{A_{V,j,l+1}}\right)^{-1}\right] \cdot \frac{\dot{m}_{V,j,l+1}}{\dot{m}_{C,j,l+1}} \cdot \left(1 - \frac{\dot{m}_{V,j,l+1}}{\dot{m}_{C,j,l+1}}\right) \tag{54}$$

with $\frac{A_{C,j,l+1}}{A_{V,j,l+1}} \geq 1;\ 0 \leq \frac{\dot{m}_{V,j,l+1}}{\dot{m}_{C,j,l+1}} \leq 1{,}0;\ \ 0° < \gamma_{C,j,l+1} \leq 90°$

For $\frac{A_{C,j,l+1}}{A_{V,j,l+1}} < 1$ the individual resistance of the junction shall be determined as the sum of the individual resistances of a cross-section reduction (see EN 13384-1:2015, Table B.8, shape 6 and 8) and a junction $\frac{A_{C,j,l+1}}{A_{V,j,l+1}} = 1$

where

$A_{C,j,l+1}$	cross sectional area of the collector segment j,l+1, in m^2
$A_{V,j,l+1}$	cross sectional area of the connecting flue pipe j,l+1
$\gamma_{C,j,l+1}$	angle of the connection between the connecting flue pipe j,l+1 and the collector segment j,l+1, in °
$\zeta_{13C,j,l+1}$	pressure resistance coefficient of the connection between the connecting flue pipe j,l+1 and the collector segment j,l+1
$\rho_{mC,j,l+1}$	average density of the flue gas in collector segment j,l+1, in kg/m^3
$w_{mC,j,l+1}$	average velocity of the flue gas in collector segment j,l+1, in m/s
$\dot{m}_{V,j,l+1}$	flue gas mass flow in connecting flue pipe j,l+1, in kg/s
$\dot{m}_{C,j,l+1}$	flue gas mass flow in collector segment j,l+1, in kg/s

14.7.1.4.6 Pressure loss due to the change of flue direction and mixing of the flue gas in the area of the inlet to the chimney segment ($P_{23,j}$)

For the calculation of pressure loss due to the change of flue direction and mixing of the flue gas in the area of the inlet to the chimney segment ($P_{23,j}$) see 12.2.3.3.

In Formula (40) put $A_{C,j,NCj}$ instead of $A_{V,j}$ and $\dot{m}_{C,j,NCj}$ instead of $\dot{m}_{V,j}$

where

$A_{C,j,NCj}$	cross sectional area of collector segment j,NCj, in m^2
$\dot{m}_{C,j,NCj}$	flue gas mass flow in collector segment j,NCj, in kg/s

14.7.1.5 Pressure at the inlet of the chimney segment ($P_{Z,j}$ and $P_{Zmax,j}$ or $P_{ZO,j}$ and $P_{ZOmin,j}$)

14.7.1.5.1 Draught

For the calculation of minimum and maximum draught at the inlet of the chimney segment ($P_{Z,j}$ and $P_{Zmax,j}$) see 12.1.1.

In Formula (35) put $A_{C,j+1,NCj+1}$ instead of $A_{V,j+1}$ and $\dot{m}_{C,j+1,NCj+1}$ instead of $\dot{m}_{V,j+1}$.

where

$A_{C,j+1,NCj+1}$	cross sectional area of collector segment j+1,NCj+1, in m^2

$\dot{m}_{C,j+1,NCj+1}$ flue gas mass flow in collector segment j+1,NCj+1, in kg/s

14.7.1.5.2 Positive pressure

For the calculation of the maximum and minimum differential pressure at the inlet of the chimney segment ($P_{ZO,j}$ and $P_{ZOmin,j}$) see 12.1.2.

In Formula (35) put $A_{C,j+1,NCj+1}$ instead of $A_{V,j+1}$ and $\dot{m}_{C,j+1,NCj+1}$ instead of $\dot{m}_{V,j+1}$

where

$A_{C,j+1,NCj+1}$ cross sectional area of collector segment j+1,NCj+1, in m^2

$\dot{m}_{C,j+1,NCj+1}$ flue gas mass flow in collector segment j+1,NCj+1, in kg/s.

14.7.2 Pressures required or available at the outlet of the connecting flue pipe ($P_{ZeC,j,l}$, $P_{ZOeC,j,l}$)

14.7.2.1 Required draught

The required draught $P_{ZeC,j,l}$ at the outlet of the connecting flue pipe j,l is the sum of the calculated draught $P_{Wc,j,l}$ of heating appliance j,l and the calculated pressure resistance of the flue gas pipe $P_{V,j,l}$ and the calculated pressure resistance of the air supply $P_{Bc,j,l}$ and it shall be calculated using Formula (44).

14.7.2.2 Available positive pressure

The maximum differential pressure (available positive pressure) $P_{ZOeC,j,l}$ at the outlet of the connecting flue pipe j,l is the difference of the calculated positive pressure differential $P_{WOc,j,l}$ of the heating appliance j,l and the sum of the calculated pressure resistance of the flue gas pipe $P_{V,j,l}$ and the calculated pressure resistance of the air supply $P_{Bc,j,l}$ and it shall be calculated using Formula (44c).

14.7.2.3 Calculated pressure resistance of the connecting flue pipe ($P_{V,j,l}$)

14.7.2.3.1 General

The calculated pressure resistance of the connecting flue pipe $P_{V,j,l}$ shall be calculated with the following formula:

$$P_{V,j,l} = P_{RV,j,l} - P_{HV,j,l}\text{, in Pa} \qquad (55)$$

14.7.2.3.2 Draught due to chimney effect in the connecting flue pipe ($P_{HV,j,l}$)

See EN 13384-1:2015, 5.11.3.2.

14.7.2.3.3 Pressure resistance of the connecting flue pipe ($P_{RV,j,l}$)

The pressure resistance of the connecting flue pipe $P_{RV,j}$ shall be calculated with the following formula:

$$P_{RV,j,l} = S_E\left[\left(\psi_{V,j,l}\frac{L_{V,j,l}}{D_{hV,j,l}} + \sum\zeta_{V,j,l}\right)\frac{\rho_{mV,j,l}}{2}w_{mV,j,l}^2\right] + S_{EMV,j,l}P_{23,j,l} + S_{EGV,j,l}P_{GV,j,l}\text{, in Pa} \qquad (56)$$

The pressure difference $P_{GV,j,l}$ is due to the difference between the velocity of flue gas in the connecting flue pipe and in the corresponding collector segment j. It shall be calculated with the following formula:

$$P_{\text{GV,j,l}} = \frac{\rho_{\text{mC,j,l}}}{2} \cdot w_{\text{mC,j,l}}^2 - \frac{\rho_{\text{mV,j,l}}}{2} \cdot w_{\text{mV,j,l}}^2 \text{, in Pa} \tag{57}$$

where

S_{E} flow safety coefficient

$S_{\text{EGV,j,l}}$ flow safety coefficient for change of pressure caused by change of velocity of the flue gas

$S_{\text{EGV,j,l}} = S_{\text{E}}$ for $P_{\text{GV,j,l}} \geq 0$; $S_{\text{EGV,j,l}} = 1{,}0$ for $P_{\text{GV,j,l}} < 0$

$S_{\text{EMV,j,l}}$ flow safety coefficient for $P_{\text{23C,j,l}}$ ($S_{\text{EMV,j,l}} = S_{\text{E}}$ for $P_{\text{23C,j,l}} \geq 0$; $S_{\text{EMV,j,l}} = 1{,}0$ for $P_{\text{23C,j,l}} < 0$)

$\psi_{\text{V,j,l}}$ coefficient of friction of the flue gas pipe j,l

$L_{\text{V,j,l}}$ length of the connecting flue gas pipe j,l, in m

$D_{\text{hV,j,l}}$ internal hydraulic diameter of flue gas pipe, in m

$\Sigma\zeta_{\text{V,j,l}}$ sum of resistance coefficients of the connecting flue pipe (exclusive of the mixing effects at the inlet to the chimney)

$\rho_{\text{mV,j,l}}$ average density of the connecting flue gas in the flue gas pipe, in kg/m^3

$w_{\text{mV,j,l}}$ average velocity of the connecting flue gas in the flue gas pipe, in m/s

The pressure loss $P_{\text{23C,j,l}}$ is due to the change of flow direction and mixing of flue gas in the area of the inlet into collector segment j,l. It shall be calculated with the following formulas:

$$P_{\text{23C,j,l}} = \zeta_{\text{23C,j,l}} \cdot \frac{\rho_{\text{Cm,j,l}}}{2} \cdot w_{\text{mC,j,l}}^2 \text{, in Pa} \tag{58}$$

$$\zeta_{\text{23C,j,l}} = -0{,}92 \cdot \left(1 - \frac{\dot{m}_{\text{V,j,l}}}{\dot{m}_{\text{C,j,l}}}\right)^2 - \left(\frac{\dot{m}_{\text{V,j,l}}}{\dot{m}_{\text{C,j,l}}}\right)^2 \cdot \left\{1{,}2 \cdot \left(\frac{A_{C,\text{j,l}}}{A_{\text{V,j,l}}} \cos\gamma_{\text{C,j,l}} - 1\right) + 0{,}8 \cdot \left[1 - \left(\frac{A_{C,\text{j,l}}}{A_{\text{V,j,l}}}\right)^2\right] - \left[1 - \left(\frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}}\right)^{-1}\right] \cdot \frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}} \cdot \cos\gamma_{\text{C,j,l}}\right\}$$
$$+ \left[2 - \left(\frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}}\right)^{-1}\right] \cdot \frac{\dot{m}_{\text{V,j,l}}}{\dot{m}_{\text{C,j,l}}} \cdot \left(1 - \frac{\dot{m}_{\text{V,j,l}}}{\dot{m}_{\text{C,j,l}}}\right) \tag{59}$$

with $\frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}} \geq 1;\ 0 \leq \frac{\dot{m}_{\text{V,j,l}}}{\dot{m}_{\text{C,j,l}}} \leq 1{,}0;\ 0° < \gamma_{\text{C,j,l}} \leq 90°$

For $\frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}} < 1$ the individual resistance of the junction shall be determined as the sum of the individual resistances of a cross-section reduction (see EN 13384-1:2015, Table B.8, shape 6 and 8) and a junction $\frac{A_{\text{C,j,l}}}{A_{\text{V,j,l}}} = 1$.

where

$\zeta_{\text{23C,j,l}}$ pressure resistance coefficient for change in flue gas direction and mixing at the area of flue gas inlet into collector segment j,l

$\rho_{\text{mC,j,l}}$ average density of the flue gas in collector segment j,l, in kg/m^3

$w_{\text{mC,j,l}}$ average flue gas velocity in collector segment j,l, in m/s

$\dot{m}_{V,j,l}$ flue gas mass flow in connecting flue pipe j,l, in kg/s

$\dot{m}_{C,j,l}$ flue gas mass flow in collector segment j,l, in kg/s

$A_{V,j,l}$ cross sectional area of connecting flue pipe j,l, in m^2

$A_{C,j,l}$ cross sectional area of collector segment j,l, in m^2

$\gamma_{C,j,l}$ angle of connection between connecting flue pipe and the collector segment j,l, in °

14.7.2.3.4 Coefficient of flow resistance (ζ)

For the calculation of the coefficient of flow resistance (ζ) see EN 13384-1:2015, 5.10.3.4.

14.7.2.4 Pressure resistance of the air supply ($P_{B,j,l}$)

For the calculation of the pressure resistance of the air supply ($P_{B,j,l}$) see EN 13384-1:2015, 5.11.4.

14.8 Inner wall temperature ($T_{iobC,j,l}$)

For the calculation of the inner wall temperature ($T_{iobC,j,l}$) see EN 13384-1:2015, 5.12.

15 Balanced flue chimney

15.1 Principle of the calculation method

The calculation is based upon determining the mass flow distribution of the flue gas in the chimney and the mass flow distribution of the supply air in the air supply duct which fulfils the pressure equilibrium condition at each flue gas inlet to the chimney (see Figure 6). After such a distribution has been found three requirements shall be verified:

a) the mass flow requirements (Formulas (4) and (5))

b) the pressure requirement for the flue gas for minimum draught or maximum positive pressure (Formulas (61) or (61a) and (61b))

c) the pressure requirement for maximum draught or minimum positive pressure (Formulas (6a) or (6d))

d) the temperature requirement (Formula (7))

15.2 Pressure equilibrium condition

For negative pressure chimneys the Formulas (1), (2) and (3) shall be fulfilled at all relevant operating conditions for each chimney segment j and also at the pressure equalizing opening for which j = 0 shall be used.

For positive pressure chimneys the Formulas (3a), (3b) and (3c) shall be fulfilled at all relevant operating conditions for each chimney segment j. The pressure resistance for the air supply of the heating appliance j connected to a balanced flue chimney $P_{Bc,j}$ shall be calculated using the following formula:

$$P_{Bc,j} = \sum_{k=j}^{N} \left(P_{RB,k} + P_{HB,k}\right) + \left(P_{RBV,j} + P_{HBV,j}\right) \text{, in Pa} \quad (60)$$

where

$P_{\mathrm{Bc,j}}$ pressure resistance of the air supply of the heating appliance j, in Pa

$P_{\mathrm{RB,k}}$ pressure resistance of the air supply duct of the chimney segment k, in Pa

$P_{\mathrm{HB,k}}$ draught due to chimney effect in the air supply duct of chimney segment k, in Pa

$P_{\mathrm{RBV,j}}$ pressure resistance of the air supply duct of the connection pipe j, in Pa

$P_{\mathrm{HBV,j}}$ draught due to chimney effect in the air supply duct of the connection pipe j, in Pa

N number of appliances connected to the chimney

The inlet/outlet construction is assumed to be designed such that wind effects are minimized. Consequently P_{L} = 0 and is omitted from the formulas.

15.3 Mass flow requirement

The Formulas (4) and (5) shall be fulfilled.

15.4 Pressure requirements

15.4.1 Negative pressure chimneys

For negative pressure chimneys it has to be additional checked that the negative pressure (minimum draught) in the chimney ($P_{\mathrm{Z,j}}$) is more than or equal to the negative pressure in the in air supply duct at the same point. The check on this pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

At all the entry points in the flue and for all the system operating conditions, the following formula shall be verified:

$$P_{\mathrm{Z,j}} \geq \sum_{k=j}^{N} \left(P_{\mathrm{RB,k}} + P_{\mathrm{HB,k}} \right), \text{ in Pa} \qquad (61)$$

where

$P_{\mathrm{Z,j}}$ Draught at the flue gas inlet to the chimney segment j, in Pa

$P_{\mathrm{RB,k}}$ Pressure resistance of the air supply duct of the chimney segment k, in Pa

$P_{\mathrm{HB,k}}$ draught due to chimney effect in the air supply duct of chimney segment k, Pa

If required it has to be additionally checked that the negative pressure (draught) in the chimney ($P_{\mathrm{Zmax,j}}$) is less than or equal to the maximum allowed draught ($P_{\mathrm{Zemax,j}}$) caused by the heating appliance. The relation (6a) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_{L} = 258,15 K (t_{L} = -15 °C, see EN 13384-1).

15.4.2 Positive pressure chimneys

For positive pressure chimneys it has to be additionally checked that the maximum pressure difference between the connecting flue pipe and/or in the chimney and the air supply duct is not higher than the excess pressure for which both are designated. The check on the pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

$$P_{\text{ZO,j}} + \sum_{k=\text{j}}^{N} \left(P_{\text{RB,k}} + P_{\text{HB,k}} \right) \leq P_{\text{Zexcess}} \text{ , in Pa} \tag{61a}$$

$$P_{\text{ZO,j}} + P_{\text{V,j}} + \sum_{k=\text{j}}^{N} \left(P_{\text{RB,k}} + P_{\text{HB,k}} \right) + P_{\text{RBV,j}} + P_{\text{HBV,j}} \leq P_{\text{ZVexcess}} \text{ , in Pa} \tag{61b}$$

where

$P_{\text{ZO,j}}$ positive pressure at the flue gas inlet to the chimney segment j, in Pa

$P_{\text{V,j}}$ calculated pressure resistance of the connecting flue pipe of chimney segment j, in Pa

$P_{\text{Z excess}}$ the maximum allowed pressure from the designation of the chimney, in Pa

$P_{\text{ZV excess}}$ the maximum allowed pressure from the designation of the connecting flue pipe, in Pa

$P_{\text{RB,k}}$ pressure resistance of the air supply duct of the chimney segment k, in Pa

$P_{\text{HB,k}}$ draught due to chimney effect in the air supply duct of chimney segment k, in Pa

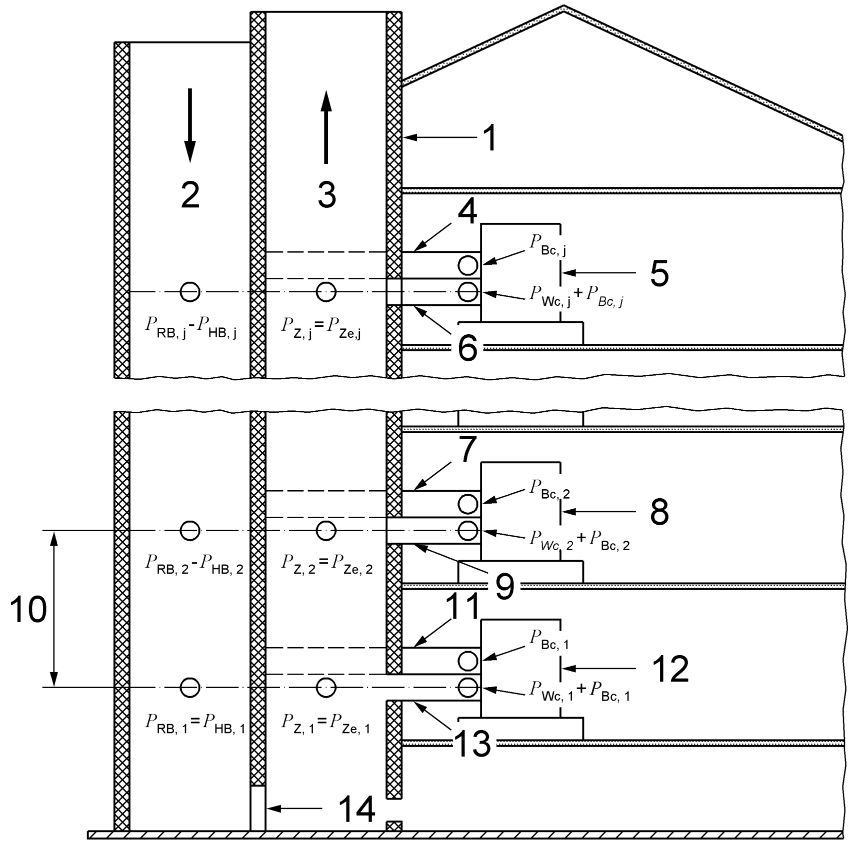
$P_{\text{RBV,j}}$ pressure resistance of the air supply duct of the connection pipe j, in Pa

$P_{\text{HBV,j}}$ draught due to chimney effect in the air supply duct of the connection pipe j, in Pa

N number of appliances connected to the chimney

If required it has to be additionally checked that the positive pressure in the chimney ($P_{\text{ZOmin,j}}$) is more than or equal to the minimum allowed positive pressure ($P_{\text{ZOemin,j}}$) caused by the heating appliance. The relation (6d) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of T_{L} = 258,15 K (t_{L} = -15 °C, see EN 13384-1).



Key

1	balanced flue chimney	8	heating appliance 2
2	combustion air duct	9	connecting flue pipe 2
3	flue duct	10	chimney segment 1
4	connecting air pipe j	11	connecting air supply pipe
5	heating appliance j	12	heating appliance 1
6	connecting flue pipe j	13	connecting flue pipe 1
7	connecting air supply pipe 2	14	pressure equalizing opening (only for negative pressure chimneys)

Figure 6 — Example for numbering pressure values and temperature values of balanced flue installations serving more than one heating appliance

15.5 Temperature requirements

The Formula (7) shall be fulfilled.

15.6 Calculation procedure for balanced flue chimneys

For the calculation of the pressure and temperature values in a balanced flue chimney serving more than one heating appliance an iterative procedure is necessary using pre-estimated values (see 15.8.2.9). This calculation procedure is based on the procedure as described in 5.6.

Each iteration consists e.g. of the following two phases:

Phase 1

Calculate variables starting from the lowest node (see Figure 6) up to the outlet to the atmosphere as follows:

— for negative pressure chimneys at the pressure equalizing opening, if any:

  — mass flow of the supply air at the pressure equalizing opening

$$\dot{m}_{B,0} = \sqrt{\frac{2 \cdot P_{Z,0} - P_{B,0}}{\rho_{\alpha} \cdot \zeta_{,0}}} \cdot A_0 \cdot \rho_{B,0} \text{, in kg/s} \tag{62}$$

where

$\dot{m}_{B,0}$ mass flow of the supply air in the chimney segment 0, in kg/s

$\zeta_{,0}$ coefficient of flow resistance through the pressure equalizing opening. A value of 3,0 shall be used unless other values are given by the manufacturer.

$P_{Z,0}$ draught in the chimney at the pressure equalizing opening (calculated according to EN 13384-1:2015, 5.11), in Pa

A_0 cross-sectional area of the pressure equalizing opening, in m^2

$\rho_{B,0}$ density of the supply air in the chimney segment 0, in kg/m^3

$P_{B,0}$ draught in the air supply duct at the pressure equalizing opening, in Pa

— in each flue duct and air supply duct of the connection pipes:

  — mass flow of the flue gas and supply air flow (they are equal to the mass flows at the outlet and inlet of the appliance);

  — average density of the flue gas (using Formula (27)) and supply air (see Formula (116));

  — average velocity of the flue gas (using Formula (28)) and supply air (see Formula (117)) ;

  — temperature of the flue gas and supply air at the end of the connection pipes (see EN 13384-1:2015, 5.8, or in case of concentric ducts Formulas (97) and (99));

  — average temperature of the flue gas and supply air (see EN 13384-1:2015, 5.8 or in case of concentric ducts Formulas (100) and (101)).

— in each flue duct and air supply duct of the chimney segments:

  — mass flow of the flue gas after merging and mass flow of the supply air before splitting using Formula (8) for flue gas and Formula (63) for supply air;

  — temperature of the flue gas/air after merging (using Formula (9) for flue gas, whilst the temperature of the supply air shall be equal upstream and downstream the connection of the air inlet pipe and the air inlet duct);

  — average density of the flue gas (using Formula (28)) and supply air (see Formula (116));

  — average velocity of the flue gas (using Formula (29)) and supply air (see Formula (117));

  — temperature of the flue gas and supply air at the end of the chimney segments (see Formulas (75) and (77) or EN 13384-1:2015, 5.8);

— average temperature of the flue gas and supply air (see EN 13384-1:2015, 5.8 or in case of concentric ducts Formulas (78) and (79)).

Phase 2

For negative pressure chimneys calculate the real draught values in each node tracking the chimney backwards from the outlet into the atmosphere down to the node that is at the greatest distance from it:

— draught due to chimney effect of the chimney segment (using Formulas (31) and (104));

— pressure resistance in the chimney segment (using Formula (32));

— draught at the inlet of the chimney segment (using Formula (2));

— pressure resistance in the chimney segment at the pressure equalizing opening, if any (using Formula (32));

— draught at the inlet of the chimney segment at the pressure equalizing opening, if any, (using Formula (2)).

For positive pressure chimneys calculate the real pressure values in each node tracking the chimney backwards from the outlet into the atmosphere down to the node that is at the greatest distance from it:

— draught due to chimney effect of the chimney segment (using Formulas (31) and (104));

— pressure resistance in the chimney segment (using Formula (32));

— positive pressure at the inlet of the chimney segment (using Formula (3b)).

The iteration described above (phase 1 and phase 2) at the working conditions under consideration shall be continued until the pressure equilibrium condition is fulfilled (Formula (1)).

15.7 Mass flow of the supply air

In each point of connection between the air supply duct of the chimney segments and the air supply duct of the connection pipes the following formula shall be used:

$$\dot{m}_{\mathrm{B,j+1}} = \dot{m}_{\mathrm{BV,j}} + \dot{m}_{\mathrm{B,j}} \text{, in kg/s} \tag{63}$$

where

$\dot{m}_{\mathrm{B,j+1}}$, $\dot{m}_{\mathrm{BV,j}}$, $\dot{m}_{\mathrm{B,j}}$ mass flow of the supply air in the air supply ducts

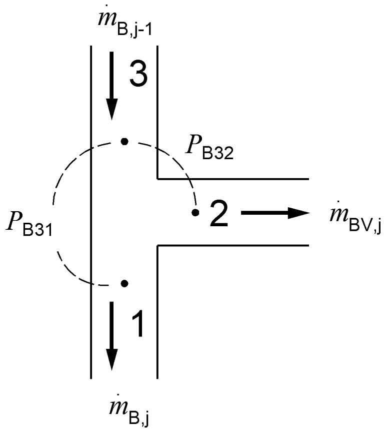


Figure 7 — Pressure loss P_{23j} due to the change of flow direction and mixing of flue gas in the area of the inlet into chimney segment j

15.8 Determination of the temperatures in balanced flue chimneys

15.8.1 Separate ducts

When the thermal resistance between the flue duct and the air supply duct is equal to or higher than 0,65 $\frac{m^2K}{W}$ the determination of the temperatures of the flue gas for separate ducts shall be calculated according to Clause 9. The temperature of the supply air within the air ducts shall be taken equal to the external air temperature.

When the thermal resistance between the flue duct and the air supply duct is less than 0,65 $m^2 \cdot K/W$ but equal to or higher than the thermal resistance of the outer duct walls the determination of the temperatures of the flue gas for separate ducts shall be calculated according to Clause 9. The mean temperature of the supply air in the segment j of the air supply duct $T_{mB,j}$ shall be calculated using the following formula:

$$T_{mB,j} = \frac{1}{\frac{0,7}{T_L} + \frac{0,3}{T_{m,j}}} \text{, in K} \tag{64}$$

where

T_L is the external air temperature, in K

$T_{m,j}$ is the mean temperature of the flue gas in the segment j, in K

Otherwise the determination of the temperatures shall be undertaken in a similar way as described in 15.8.2.

15.8.2 Concentric ducts

15.8.2.1 General

The following calculations are valid for a segment length up to 3 m.

For segments more than 3 m subdivide the construction into more segments and redo the calculation.

15.8.2.2 Principle of calculation for the determination of the temperature

In addition to procedure described in 5.6 the calculation of the temperatures in the concentric ducts depends on assuming initial values for unknown temperatures. The formulas in 15.8.2 are used iteratively until the conditions in 15.8.2.10 are fulfilled.

15.8.2.3 Coefficient of heat transmission between the flue and the air supply passage

For the calculation of the coefficient of heat transmission between the flue and the air supply passage for concentric ducts (see Figure 8) the following formula shall be used:

$$k_{,j} = \frac{1}{\frac{1}{\alpha_{i,j}} + S_H \cdot \left[\left(\frac{1}{\Lambda} \right) + \frac{D_h}{D_{ha} \cdot \alpha_{a,j} \cdot S_{rad}} \right]}, \text{ in } \frac{W}{m^2 K} \quad (65)$$

where

$k_{,j}$ coefficient of heat transmission between the flue and the air supply passage of the chimney segment j, in $\frac{W}{m^2K}$

$\alpha_{i,j}$ coefficient of heat transfer between the flue gas and the inner surface of the flue duct of the chimney segment j, in $\frac{W}{m^2K}$

$\alpha_{a,j}$ coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment j, in $\frac{W}{m^2K}$

D_h hydraulic diameter of the flue, in m

D_{ha} hydraulic diameter of the outside of the flue duct, in m

S_H correction factor for temperature instability

$\left(\frac{1}{\Lambda}\right)$ thermal resistance of the flue duct, in $\frac{W}{m^2K}$

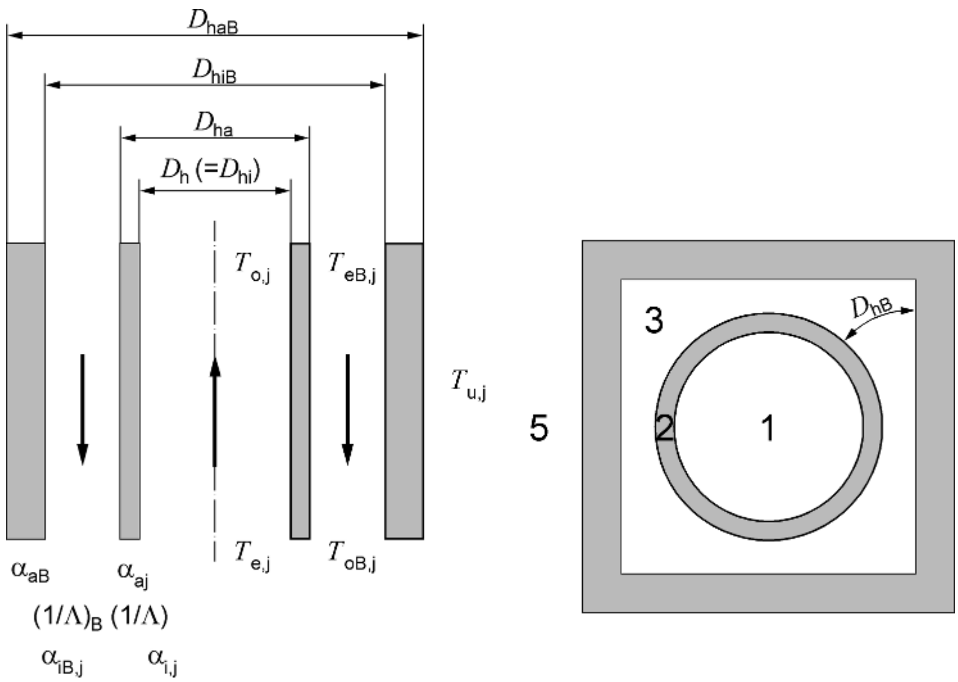
S_{rad} correction factor for radiation from the outer surface of the flue duct to the inner surface of the air supply duct

For balanced flue chimneys with concentric ducts the correction factor S_H shall be taken as 1.

In order to account for the effects of radiation from the outer surface of the flue duct to the inner surface of the air supply duct the calculation of the coefficient of heat transmission $k_{,j}$ includes a correction factor for radiation S_{rad}, for which the value 2 shall be taken.

For chimney segments in which the inner wall temperature of the flue duct is always lower than the condensing temperature of the flue gas the value S_{rad} = 1 should be taken.

For a more detailed evaluation of the heat transfer by radiation see EN 13384-1:2015, 7.8.3.



1 flue (with flue gas)
2 flue duct
3 air supply passage (with supply air)
4 air supply duct
5 ambient air

Figure 8 — Definition of the symbols used for the calculation of concentric balanced flue systems

For the calculation of the coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment j $\alpha_{a,j}$ the following formulas shall be used:

$$\alpha_{a,j} = \frac{\lambda_{B,j} \cdot Nu_{a,j}}{D_{hB}}, \text{ in } \frac{W}{m^2K} \quad (66)$$

with

$$D_{hB} = \frac{4 A_B}{U_a + U_{iB}}, \text{ in m} \quad (67)$$

$$Nu_{a,j} = 0{,}86 \cdot \left(\frac{D_{hB}}{D_{ha}} \right)^{0,16} \cdot Nu_{B,j} \quad (68)$$

and

$$Nu_{B,j} = \left[\frac{\psi_{B,j}}{\psi_{smoothB,j}} \right]^{0,67} \cdot 0{,}0214 \cdot \left(Re_{B,j}^{\;0,8} - 100 \right) \cdot Pr_{B,j}^{\;0,4} \cdot \left(1 + \frac{D_{hB}}{L_{,j}} \right)^{0,67} \quad (69)$$

with

$$Re_{B,j} = \frac{w_{\mathrm{mB,j}} \cdot D_{\mathrm{hB}} \cdot \rho_{\mathrm{mB,j}}}{\eta_{\mathrm{B}}} \tag{70}$$

where

$\alpha_{a,j}$	coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment j, in $\frac{\mathrm{W}}{\mathrm{m^2 \cdot K}}$
$\lambda_{B,j}$	thermal conductivity of the supply air in the chimney segment j, in $\frac{\mathrm{W}}{\mathrm{m \cdot K}}$
$Nu_{a,j}$	Nusselt number for the outside of the flue duct of the chimney segment j
D_{hB}	hydraulic diameter of the air supply passage, in m
A_B	cross-sectional area of the air supply passage, in m²
U_{iB}	circumference of the inside of the air supply duct, in m
U_a	circumference of the outside of the flue duct, in m
D_{ha}	hydraulic diameter of the outside of the flue duct, in m
$Nu_{B,j}$	Nusselt number for a reference pipe flow
$\psi_{B,j}$	the higher of the value of the coefficient of friction of the inside of the air supply duct and the outside of the flue duct of the chimney segment j
$\psi_{smoothB,j}$	coefficient of friction of the air supply for hydraulically smooth flow of the chimney segment j
$Re_{B,j}$	Reynolds number of the air supply passage of the chimney segment j
$Pr_{B,j}$	Prandtl number of the supply air in the chimney segment j
$L_{,j}$	length of the chimney segment j, in m
$w_{mB,j}$	average velocity of the supply air in chimney segment j, m/s
$\rho_{mB,j}$	average density of the supply air in chimney segment j, kg/m^3
$\eta_{B,j}$	dynamic viscosity of the supply air in chimney segment j, Ns/m^2

15.8.2.4 Coefficient of heat transmission between the supply air and the ambient air

The coefficient of heat transmission between the supply air and the ambient air shall be calculated using the following formula in case of concentric ducts:

$$k_{B,j} = \frac{1}{\frac{1}{\alpha_{iB,j}} + S_H \cdot \left[\left(\frac{1}{\Lambda} \right)_B + \frac{D_{hiB}}{D_{haB} \cdot \alpha_{aB,j}} \right]}, \text{ in } \frac{W}{m^2 \cdot K} \tag{71}$$

where

$k_{B,j}$ coefficient of heat transmission between the supply air and the ambient air of chimney segment j, in $\frac{W}{m^2 \cdot K}$

$\alpha_{iB,j}$ coefficient of heat transfer between the supply air and the inner surface of the air supply duct of chimney segment j, in $\frac{W}{m^2 \cdot K}$

$\left(\frac{1}{\Lambda} \right)_B$ thermal resistance of the air supply duct, in $\frac{W}{m^2 \cdot K}$

D_{haB} hydraulic diameter of the outside of the air supply duct, in m

D_{hiB} hydraulic diameter of the inside of the air supply duct, in m

$\alpha_{aB,j}$ coefficient of heat transfer between the outside of the air supply duct and the ambient air, in $\frac{W}{m^2 \cdot K}$

S_H correction factor for temperature instability

For balanced flue chimneys with concentric ducts the correction factor S_H shall be taken as 1.

For the calculation of $\alpha_{iB,j}$ the following formula shall be used:

$$\alpha_{iB,j} = \frac{\lambda_{B,j} \cdot Nu_{iB,j}}{D_{hB}}, \text{ in } \frac{W}{m^2 \cdot K} \tag{72}$$

with

$$Nu_{iB,j} = \left[1 - 0{,}14 \cdot \left(\frac{D_{ha}}{D_{hiB}} \right)^{0{,}6} \right] \cdot Nu_{B,j} \tag{73}$$

and $Nu_{B,j}$ according to Formula (69) and $D_{hB,j}$ according to Formula (70).

where

$\lambda_{B,j}$ thermal conductivity of the supply air in of the chimney segment j, in $\frac{W}{m^2 \cdot K}$

$Nu_{iB,j}$ Nusselt number for the inside of the air supply duct of the chimney segment j

$Nu_{B,j}$ Nusselt number for a reference pipe flow

D_{hB} hydraulic diameter of the air supply passage, in m

D_{hiB} hydraulic diameter of the inside of the air supply duct, in m

D_{ha} hydraulic diameter of the outside of the flue duct, in m

15.8.2.5 Cooling value of the flue duct

The cooling value of the flue duct shall be calculated using the following formula:

$$K_{,j} = \frac{k_{,j} \cdot U \cdot L_{,j}}{\dot{m}_{,j} \cdot c_{p,j}} \tag{74}$$

where

$K_{,j}$ cooling value of the flue duct of the chimney segment j

$k_{,j}$ coefficient of heat transmission between flue and the air supply passage of the chimney segment j, in $\frac{W}{m^2 \cdot K}$

U circumference of the flue, in m

$L_{,j}$ length of the chimney segment j, in m

$\dot{m}_{,j}$ mass flow of the flue gas in the chimney segment j, in kg/s

$c_{p,j}$ specific heat capacity of the flue gas in the chimney segment j, $\frac{J}{kg \cdot K}$

15.8.2.6 Cooling value of the air supply duct

The cooling value of the air supply duct shall be calculated using the following formula:

$$K_{B,j} = \frac{k_{B,j} \cdot U_{iB} \cdot L_{B,j}}{\dot{m}_{B,j} \cdot c_{pB,j}} \tag{75}$$

where

$K_{B,j}$ cooling value of the air supply duct of the chimney segment j

$k_{B,j}$ coefficient of heat transmission between the supply air and the ambient air of the chimney segment j, in $\frac{W}{m^2 \cdot K}$

U_{iB} circumference of the inside of the air supply duct, in m

$L_{B,j}$ length of the chimney segment j, in m

$\dot{m}_{B,j}$ mass flow of the supply air in the chimney segment j, in g/s

$c_{pB,j}$ specific heat capacity of the supply air in the chimney segment j, in $\frac{J}{kg \cdot K}$

15.8.2.7 Flue gas temperature at the end of the chimney segment

The flue gas temperature at the end of the flue duct of chimney segment j shall be calculated using Formula (76) when starting the iteration from an initial estimate for each $T_{\text{eB,j}}$

$$T_{\text{o,j}} = \frac{\left(2 - K_{\text{,j}}\right)\cdot\left(2 + K_{\text{B,j}}\right)\cdot T_{\text{e,j}} \; + \; 2\cdot K_{\text{,j}}\cdot\left(E_{\text{,j}}\cdot T_{\text{e,j}} + 2\cdot T_{\text{eB,j}} + K_{\text{B,j}}\cdot T_{\text{u,j}}\right)}{\left(2 + K_{\text{,j}}\right)\cdot\left(2 + K_{\text{B,j}}\right) \; + \; 2\cdot K_{\text{,j}}\cdot E_{\text{,j}}}, \text{ in K} \tag{76}$$

or Formula (77) when starting the iteration from an estimate for $T_{\text{oB,1}}$

$$T_{\text{o,j}} = \frac{\left(2 - K_{\text{,j}}\right)\cdot\left(2 - K_{\text{B,j}}\right)\cdot T_{\text{e,j}} \; - \; 2\cdot K_{\text{,j}}\cdot\left(E_{\text{,j}}\cdot T_{\text{e,j}} - 2\cdot T_{\text{oB,j}} + K_{\text{B,j}}\cdot T_{\text{u,j}}\right)}{\left(2 + K_{\text{,j}}\right)\cdot\left(2 - K_{\text{B,j}}\right) \; - \; 2\cdot K_{\text{,j}}\cdot E_{\text{,j}}}, \text{ in K} \tag{77}$$

$$E_{\text{,j}} = \frac{\dot{m}_{\text{,j}}\cdot c_{\text{p,j}}}{\dot{m}_{\text{B,j}}\cdot c_{\text{pB,j}}} \tag{78}$$

where

$T_{\text{o,j}}$	temperature of the flue gas at the end of the chimney segment j, in K
$T_{\text{e,j}}$	temperature of the flue gas at the beginning of the chimney segment j, in K
$T_{\text{oB,j}}$	temperature of the supply air at the end of chimney segment j, in K
$T_{\text{eB,j}}$	temperature of the supply air at the beginning of the chimney segment j, in K
$T_{\text{u,j}}$	ambient air temperature of the chimney segment j, in K
$K_{\text{,j}}$	cooling value of the flue duct of the chimney segment j
$K_{\text{B,j}}$	cooling value of the air supply duct of the chimney segment j
$\dot{m}_{\text{,j}}$	mass flow of the flue gas in the chimney segment j, in kg/s
$c_{\text{p,j}}$	specific heat capacity of the flue gas in the chimney segment j, in $\frac{\text{J}}{\text{kg}\cdot\text{K}}$
$\dot{m}_{\text{B,j}}$	mass flow of the supply air in the chimney segment j, in kg/s
$c_{\text{pB,j}}$	specific heat capacity of the supply air in the chimney segment j, in $\frac{\text{J}}{\text{kg}\cdot\text{K}}$
$E_{\text{,j}}$	heat flux ratio between the flue gas and the supply air in the chimney segment j

The supply air temperature at the end of the chimney segment j for concentric ducts shall be calculated using Formula (79) when starting the iteration from an initial estimate for each $T_{\text{eB,j}}$

$$T_{\text{oB,j}} = T_{\text{e,j}} + T_{\text{o,j}} - T_{\text{eB,j}} - \frac{2}{K_{\text{,j}}}\left(T_{\text{e,j}} - T_{\text{o,j}}\right), \text{ in K} \tag{79}$$

or Formula (80) when starting the iteration from an estimate for $T_{\text{oB,1}}$

$$T_{\text{eB,j}} = T_{\text{e,j}} + T_{\text{o,j}} - T_{\text{oB,j}} - \frac{2}{K_{\text{,j}}}\left(T_{\text{e,j}} - T_{\text{o,j}}\right), \text{ in K} \tag{80}$$

where

$T_{o,j}$ temperature of the flue gas at the end of chimney segment j, in K

$T_{e,j}$ temperature of the flue gas at the beginning of chimney segment j, in K

$T_{oB,j}$ temperature of the supply air at the end of chimney segment j, in K

$T_{eB,j}$ temperature of the supply air at the beginning of chimney segment j, in K

$K_{,j}$ cooling value of the flue duct of chimney segment j

NOTE The formulas above are derived assuming that the heat exchange can be approximately calculated from the difference in mean temperatures.

15.8.2.8 Temperature of the flue gas averaged over the length of a chimney segment

The temperature of the flue gas averaged over the length of the chimney segment j for a concentric duct shall be calculated using the following formula:

$$T_{m,j} = \frac{T_{e,j} + T_{o,j}}{2} \text{, in K} \tag{81}$$

where

$T_{m,j}$ temperature of the flue gas averaged over the length of the chimney segment j, in K

$T_{o,j}$ temperature of the flue gas at the end of the chimney segment j, in K

$T_{e,j}$ temperature of the flue gas at the beginning of chimney segment j, in K

15.8.2.9 Temperature of the supply air averaged over the length of a chimney segment

The temperature of the supply air averaged over the length of the chimney segment for a concentric duct shall be calculated using the following formula:

$$T_{mB,j} = \frac{T_{eB,j} + T_{oB,j}}{2} \text{, in K} \tag{82}$$

where

$T_{mB,j}$ temperature of the supply air averaged over the length of chimney segment j, in K

$T_{oB,j}$ temperature of the supply air at the end of chimney segment j, in K

$T_{eB,j}$ temperature of the supply air at the beginning of chimney segment j, in K

15.8.2.10 Iteration

For the calculation of $T_{o,j}$ and $T_{oB,j}$ it is necessary to know the relevant supply air temperatures $T_{eB,j}$ for all nodes. For the supply air temperature at the entrance of the topmost chimney segment $Nseg$ the following formula shall be used:

$$T_{eB,Nseg} = T_L \text{, in K} \tag{83}$$

Starting from an initial estimate for $T_{eB,j}$ use the Formulas (64) to (82) repeatedly, adapting $T_{eB,j}$ for j < $Nseg$ until the following conditions are fulfilled:

$$\left| T_{eB,j} - T_{oB,j+1} \right| \leq \frac{1}{Nseg} \text{ for j} < Nseg \text{, in K} \tag{84}$$

and when calculating the supply air temperatures from the bottom to the top of the concentric balanced flue chimney use:

$$T_{oB,j} = T_{eB,j-1} \text{ for j > 1, in K} \tag{85}$$

$T_{oB,1}$ shall be searched for iteratively until the following condition is fulfilled:

$$\left|T_{eB,Nseg} - T_L\right| \leq 1 \text{ , in K} \tag{86}$$

where

$T_{eB,Nseg}$ temperature of the supply air at the entrance of chimney segment *Nseg,* in K

T_L temperature of the external air, in K

$T_{eB,j}$ temperature of the supply air at the entrance of chimney segment j, in K

$T_{oB,j+1}$ temperature of the supply air at the end of chimney segment j+1, in K

Nseg number of chimney segments used in the calculation

NOTE Other mathematical methods for solving the Formulas (64) to (83) can be used as long as the conditions (86) and (88) are fulfilled.

15.8.3 Concentric connection pipes

15.8.3.1 Coefficient of heat transmission between the flue and the air supply passage of concentric connection pipes

The coefficient of heat transmission between the flue gas and the supply air of concentric connection pipe j shall be calculated using the following formula.

$$k_{V,j} = \frac{1}{\dfrac{1}{\alpha_{iV,j}} + S_H\left[\left(\dfrac{1}{\Lambda}\right)_{V,j} + \dfrac{D_{hV,j}}{D_{haV,j} \cdot \alpha_{aV,j} \cdot S_{rad}}\right]} \text{, in } \frac{W}{m^2 \cdot K} \tag{87}$$

where

$k_{V,j}$ coefficient of heat transmission between the flue gas and the supply air of the connection pipe j, in $\frac{W}{m^2 \cdot K}$

S_H correction factor for temperature instability

$\left(\frac{1}{\Lambda}\right)_{V,j}$ thermal resistance of the flue duct of the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

where

$D_{hV,j}$ hydraulic diameter of the flue of concentric connection pipe j, in m

$D_{haV,j}$ hydraulic diameter of the outside of the flue duct of the concentric connection pipe j, in m

$\alpha_{iV,j}$ coefficient of heat transfer between the flue gas and the inner surface of the flue duct of the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$\alpha_{aV,j}$ coefficient of heat transfer between the supply air and the outer surface of the flue duct of the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

S_{rad} correction factor for the heat transfer by radiation

For concentric connection pipes the correction factor S_H shall be taken as 1.

In order to account for the effects of radiation from the outer surface of the flue duct to the inner surface of the air supply duct of the concentric connection pipes the calculation of k_j includes a correction factor for radiation S_{rad}, for which the value 2 shall be taken.

For concentric connection pipes in which the inner wall temperature of the flue duct is always lower than the condensing temperature of the flue gas the value S_{rad} = 1 should be taken.

For $\alpha_{aV,j}$ the following formula shall be used:

$$\alpha_{aV,j} = \frac{\lambda_{BV,j} \cdot \mathrm{Nu}_{aV,j}}{D_{hBV,j}}, \text{ in } \frac{W}{m^2 \cdot K} \tag{88}$$

with

$$D_{hBV,j} = \frac{4 \cdot A_{BV,j}}{U_{aV,j} + U_{iBV,j}}, \text{ in m} \tag{89}$$

$$Nu_{aV,j} = 0{,}86 \cdot \left(\frac{D_{hBV,j}}{D_{hVa,j}}\right)^{0{,}16} \cdot Nu_{BV,j}, \tag{90}$$

and

$$Nu_{BV,j} = \left[\frac{\psi_{BV,j}}{\psi_{smoothBV,j}}\right]^{0{,}67} \cdot 0{,}0214 \cdot \left(Re_{BV,j}{}^{0{,}8} - 100\right) \cdot Pr_{BV,j}{}^{0{,}4} \cdot \left(1 + \frac{D_{hBV,j}}{L_{V,j}}\right)^{0{,}67} \tag{91}$$

$$Re_{BV,j} = \frac{w_{BV,j} \cdot D_{hBV,j}}{\nu_{BV,j}} \tag{92}$$

where

$\lambda_{BV,j}$ thermal conductivity of the supply air in the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$Nu_{aV,j}$ Nusselt number for the outside of the flue duct of the connecting air pipes j

$D_{hBV,j}$ hydraulic diameter of the air supply passage of the concentric connection pipe j, in m

$A_{BV,j}$ cross-sectional area of the air supply passage of the concentric connection pipe j, in m²

$D_{hVai,j}$ hydraulic diameter of the outside of the flue duct of the concentric connection pipe j, in m

$U_{iBV,j}$ circumference of the inside of the air supply duct of the concentric connection pipe j, in m

$U_{aVi,j}$ circumference of the outside of the flue duct of the concentric connection pipe j, in m

$Nu_{BV,j}$ Nusselt number for a reference pipe flow for concentric connection pipe j

$\psi_{BV,j}$ the higher of the value of the coefficient of friction of the inside of the air supply duct and the outside of the flue duct of the concentric connection pipe j

$\psi_{smoothBV,j}$ coefficient of friction of the air supply passage of the concentric connection pipe j for hydraulically smooth flow

$Re_{BV,j}$ Reynolds number of the air supply passage of the concentric connection pipe j

$Pr_{BV,j}$ Prandtl number of the supply air in the concentric connection pipe j

$L_{V,j}$ length of the concentric connection pipe j, in m

15.8.3.2 Coefficient of heat transmission between the supply air and the ambient air for concentric connection pipes

15.8.3.2.1 General

The coefficient of heat transmission between the supply air and the ambient air for concentric connection pipes shall be calculated using the following formula:

$$k_{BV,j} = \frac{1}{\frac{1}{\alpha_{iBV,j}} + S_H \cdot \left[\left(\frac{1}{\Lambda} \right)_{BV,j} + \frac{D_{hiBV,j}}{D_{haBV,j} \cdot \alpha_{aBV,j}} \right]}, \text{ in } \frac{W}{m^2 \cdot K} \tag{93}$$

where

$k_{BV,j}$ coefficient of heat transmission between the supply air and the ambient air for the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$\alpha_{iBV,j}$ coefficient of heat transfer between the supply air and the inner surface of the air supply duct of the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$\left(\frac{1}{\Lambda} \right)_{BV,j}$ thermal resistance of the air supply duct of the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$D_{hiBV,j}$ hydraulic diameter of the air supply passage of the concentric connection pipe j, in m

$D_{haBV,j}$ hydraulic diameter of the outside of the air supply duct of the concentric connection pipe j, in m

S_H correction factor for temperature instability

$\alpha_{aBV,j}$ coefficient of heat transfer between the outside of the air supply duct of the concentric connection pipe j and the ambient air, in $\frac{W}{m^2 \cdot K}$

For concentric connection pipes the correction factor S_H shall be taken as 1.

For the calculation of $\alpha_{iVB,j}$ the following formulas shall be used:

$$\alpha_{iBV,j} = \frac{\lambda_{BV,j} \cdot Nu_{iBV,j}}{D_{hBV,j}}, \text{ in } \frac{W}{m^2 \cdot K} \tag{94}$$

with

$$Nu_{\text{iBV,j}} = \left[1 - 0{,}14 \cdot \left(\frac{D_{\text{haV,j}}}{D_{\text{hiB,j}}} \right)^{0{,}6} \right] \cdot Nu_{\text{BV,j}} \tag{95}$$

$Nu_{\text{BV,j}}$ according to (91) and $D_{\text{hBV,j}}$ according to (92).

where

$\lambda_{\text{BV,j}}$	thermal conductivity of the supply air in the concentric connection pipe j, in $\frac{\text{W}}{\text{m}^2 \cdot \text{K}}$
$Nu_{\text{BV,j}}$	Nusselt number for a reference pipe flow for the concentric connection pipe j
$Nu_{\text{iBV,j}}$	Nusselt number of the inside of the air supply duct of the concentric connection pipe j
$D_{\text{hBV,j}}$	hydraulic diameter of the air supply passage of the concentric connection pipe j, in m
$D_{\text{hiBV,j}}$	hydraulic diameter of the inside of the air supply duct of the concentric connection pipe j, in m
$D_{\text{haV,j}}$	hydraulic diameter of the outside of the flue duct of the concentric connection pipe j, in m

15.8.3.2.2 Cooling value of the flue duct of concentric connecting pipes

The cooling value of the flue duct of concentric connecting pipes shall be calculated using the following formula:

$$K_{\text{V,j}} = \frac{k_{\text{V,j}} \cdot U_{\text{V,j}} \cdot L_{\text{V,j}}}{\dot{m}_{\text{V,j}} \cdot c_{\text{pV,j}}} \tag{96}$$

where

$K_{\text{V,j}}$	cooling value of the flue duct of the concentric connection pipe j
$k_{\text{V,j}}$	coefficient of heat transmission between flue and the air supply passage of the concentric connection pipe j, in $\frac{\text{W}}{\text{m}^2 \cdot \text{K}}$
$U_{\text{V,j}}$	circumference of the flue of the concentric connection pipe j, in m
$L_{\text{V,j}}$	length of the concentric connection pipe j, in m
$\dot{m}_{\text{V,j}}$	flue gas mass flow in the concentric connection pipe j, in kg/s
$c_{\text{pV,j}}$	specific heat capacity of the flue gas in the concentric connection pipe j, in $\frac{\text{J}}{\text{kg} \cdot \text{K}}$

15.8.3.2.3 Cooling value of the air supply duct of concentric connection pipes

The cooling value of the air supply duct of the concentric connection pipe j shall be calculated using the following formula:

$$K_{\text{BV,j}} = \frac{k_{\text{BV,j}} \cdot U_{\text{iBV,j}} \cdot L_{\text{V,j}}}{\dot{m}_{\text{BV,j}} \cdot c_{\text{pBV,j}}} \tag{97}$$

where

$K_{BV,j}$ cooling value of the air supply duct of the concentric connection pipe j

$k_{BV,j}$ coefficient of heat transmission between the supply air and the ambient air for the concentric connection pipe j, in $\frac{W}{m^2 \cdot K}$

$U_{iBV,j}$ circumference of the inside of the air supply duct of the concentric connection pipe j, in m

$L_{V,j}$ length of the concentric connection pipe j, in m

$\dot{m}_{BV,j}$ mass flow of the supply air in the concentric connection pipe j, in kg/s

$c_{pBV,j}$ specific heat capacity of the supply air in the concentric connection pipe j, in $\frac{J}{kg \cdot K}$

15.8.3.3 Flue gas temperature at the end of the flue of concentric connection pipes ($T_{ov,j}$)

The flue gas temperature at the end of the flue of the concentric connection pipe j shall be calculated using the following formula:

$$T_{oV,j} = \frac{(2 - K_{V,j}) \cdot (2 + K_{BV,j}) \cdot T_{W,j} + 2 \cdot K_{V,j} \cdot \left(E_{V,j} \cdot T_{W,j} + 2 \cdot T_{eBV,j} + K_{BV,j} \cdot T_{uV,j}\right)}{(2 + K_{V,j}) \cdot (2 + K_{BV,j}) \; + \; 2 \cdot K_{V,j} \cdot E_{V,j}}, \text{ in K} \qquad (98)$$

with

$$E_{V,j} = \frac{\dot{m}_{V,j} \cdot c_{pV,j}}{\dot{m}_{BV,j} \cdot c_{pBV,j}} \qquad (99)$$

$$T_{eBV,j} = T_{oB,j} \qquad (100)$$

where

$T_{oV,j}$ temperature of the flue gas at the end of the flue of the concentric connection pipe j, in K

$T_{W,j}$ temperature of the flue gas at the outlet of the appliance j, in K

$T_{eBV,j}$ temperature of the supply air at the beginning of the concentric connection pipe j, in K

$T_{uV,j}$ temperature of the ambient air of the concentric connection pipe j, in K

$K_{V,j}$ cooling value of the flue duct of the concentric connection pipe j

$K_{BV,j}$ cooling value of the air supply duct of the concentric connection pipe j

$\dot{m}_{V,j}$ mass flow of the flue gas in the concentric connection pipe j, in kg/s

$c_{pV,j}$ specific heat capacity of the flue gas in the concentric connection pipe j, in $\frac{J}{kg \cdot K}$

$\dot{m}_{BV,j}$ mass flow of the supply air in the concentric connection pipe j, in kg/s

$c_{pBV,j}$ specific heat capacity of the supply air in the concentric connection pipe j, in $\frac{J}{kg \cdot K}$

$E_{V,j}$ heat flux ratio between the flue gas and the combustion air in the concentric connection pipe j

$T_{oB,j}$ temperature of the supply air at the end of chimney segment j, in K

NOTE 1 The Formulas (98) is derived assuming that the heat exchange can be approximately calculated from the difference in mean temperatures.

The supply air temperature at the end of the air supply passage of the concentric connection pipe j shall be calculated using following formula:

$$T_{\text{oBV,j}} = T_{\text{W,j}} + T_{\text{oV,j}} - T_{\text{eBV,j}} - \frac{2}{K_{\text{V,j}}}\left(T_{\text{W,j}} - T_{\text{oV,j}}\right), \text{ in K} \tag{101}$$

where

$T_{\text{oV,j}}$ temperature of the flue gas at the end of the flue of the concentric connection pipe j, in K

$T_{\text{W,j}}$ temperature of the flue gas at the outlet of the appliance j, in K

$T_{\text{oBV,j}}$ temperature of the supply air at the end of the concentric connection pipe j, in K

$T_{\text{eBV,j}}$ temperature of the supply air at the beginning of the concentric connection pipe j, in K

$K_{\text{V,j}}$ cooling value of the flue of the concentric connection pipe j

NOTE 2 In addition to the check of the temperature requirement of the chimney a check of the supply air temperature at the end of the air supply of the concentric connection pipe $T_{\text{oBV,j}}$ can also be undertaken if there exists a maximum air inlet temperature for the heating appliance given by the manufacturer.

15.8.3.4 Temperature of the flue gas averaged over the length of the concentric connection pipes

The temperature of the flue gas average over the length of the concentric connection pipe j shall be calculated using the following formula:

$$T_{\text{mV,j}} = \frac{T_{\text{W,j}} + T_{\text{oV,j}}}{2}, \text{ in K} \tag{102}$$

where

$T_{\text{mV,j}}$ temperature of the flue gas averaged over the length of the concentric connection pipe j, in K

$T_{\text{oV,j}}$ temperature of the flue gas at the end of the flue of the concentric connection pipe j, in K

$T_{\text{W,j}}$ temperature of the flue gas at the outlet of the appliance j, in K

15.8.3.5 Temperature of the supply air averaged over the length of the concentric connection pipes

The temperature of the supply air averaged over the length of the concentric connection pipe j shall be calculated using the following formula:

$$T_{\text{mBV,j}} = \frac{T_{\text{eBV,j}} + T_{\text{oBV,j}}}{2}, \text{ in K} \tag{103}$$

where

$T_{\text{mBV,j}}$ temperature of the supply air averaged over the length of the concentric connection pipe j, in K

$T_{\text{oBV,j}}$ temperature of the supply air at the end of the flue of concentric connection pipe j, in K

$T_{\text{eBV,j}}$ temperature of the supply air at the beginning of the air supply passage of the concentric connection pipe j, in K

15.9 Pressures of the air supply ducts

15.9.1 Draught due to chimney effect of the air supply duct of chimney segment j

The draught due to the chimney effect in the air supply duct for balanced flue chimney with separate ducts and for balanced flue chimney with concentric ducts with flue ducts with a thermal resistance higher 0,65 $\frac{W}{m^2 \cdot K}$ shall be taken as 0.

The draught due to the chimney effect of the air supply duct of chimney segment j of other balanced flue chimneys shall be calculated using the following formula:

$$P_{HB,j} = H_{,j}\, g\, (\rho_L - \rho_{mB,j}), \text{ in Pa} \tag{104}$$

where

$P_{HB,j}$ draught due to chimney effect of the air supply duct of chimney segment j, in Pa

$H_{,j}$ height of chimney segment j, in m

g acceleration due to gravity, shall be taken as 9,81, in m/s^2

ρ_L density of ambient air, in kg/m^3

$\rho_{mB,j}$ density of supply air averaged over the length of chimney segment j, in kg/m^3

NOTE Experience shows that a limit should be applied to the minimum cross sectional area of the air supply duct of concentric air flue systems. A factor of 1,5 times the flue cross sectional area is advised.

15.9.2 Draught due to chimney effect of the air supply duct of connection pipes

The draught due to the chimney effect of the air supply duct of connection pipes of balanced flue chimneys with separate ducts and of balanced flue chimneys with concentric ducts with flue ducts with a thermal resistance higher 0,65 $\frac{W}{m^2 \cdot K}$ shall be taken as 0.

The draught due to chimney effect of the air supply duct of the connection pipe j shall be calculated using the following formula:

$$P_{HBV,j} = H_{V,j}\, g\, (\rho_L - \rho_{mBV,j}), \text{ in Pa} \tag{105}$$

where

$P_{HBV,j}$ draught due to chimney effect in the air supply duct of the connection pipe j, in Pa

$H_{V,j}$ height of the connection pipe j, in m

g acceleration due to gravity, shall be taken as 9,81, in m/s^2

ρ_L density of the ambient air, in kg/m^3

$\rho_{mBV,j}$ density of supply air averaged over the length of the air supply duct of the connection pipe j, in kg/m^3

15.9.3 Pressure resistance of the air supply duct of the chimney segment j ($P_{RB,j}$)

The pressure resistance of the air supply duct of the chimney segment j $P_{RB,j}$ shall be calculated using the following formula:

$$P_{RB,j} = S_{EB} \cdot \left(\psi_{B,j} \cdot \frac{L_{j}}{D_{hB}} + \sum \varsigma_{B,j} \right) \cdot \frac{\rho_{mB,j}}{2} \cdot w_{mB,j}^2 + S_{EMB,j} \cdot P_{B31,j} + S_{EGB,j} \cdot P_{GB,j} \text{, in Pa} \quad (106)$$

where

$P_{RB,j}$ pressure resistance of the air supply duct of the chimney segment j, in Pa

$P_{B31,j}$ pressure loss due to the splitting of the air supply in the area of the inlet into the connecting air supply duct of the chimney segment j+1, in Pa

$P_{GB,j}$ pressure change due to change in velocity of the flow in the air supply passage of chimney segment j, in Pa

$\psi_{B,j}$ coefficient of friction of the air supply passage of the chimney segment j

$L_{,j}$ length of the chimney segment j, in m

$D_{hB,j}$ hydraulic diameter of the air supply passage of chimney segment j, in m

$\Sigma\zeta_{B,j}$ sum of coefficients of flow resistance in the air supply passage of the chimney segment j

$\rho_{mB,j}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

$w_{mB,j}$ velocity of the supply air based on the average density of the supply air in the chimney segment j, in m/s

S_{EB} flow safety coefficient for the air supply duct

$S_{EMB,j}$ flow safety coefficient for the pressure resistance due to splitting of the air supply ($S_{EMB,j} = S_{EB}$ for $P_{B31,j} \geq 0$ and $S_{EMB,j}$ = 1,0 for $P_{B31,j} < 0$)

$S_{EGB,j}$ flow safety coefficient for the pressure resistance due to change of flow velocity in the chimney segment j ($S_{EGB,j} = S_{EB}$ for $P_{GB,j} \geq 0$ and $S_{EGB,j}$ = 1,0 for $P_{GB,j} < 0$)

The pressure change due to change of velocity of the flow $P_{GB,j}$ in the air supply passage in chimney segment j shall be calculated with the following formula:

$$P_{GB,j} = \frac{\rho_{mB,j}}{2} \cdot w_{mB,j}^2 - \frac{\rho_{mB,j+1}}{2} \cdot w_{mB,j+1}^2 \text{ for j < N, in Pa} \quad (107)$$

$$P_{GB,N} = \frac{\rho_{mB,N}}{2} \cdot w_{mB,N}^2 \text{ for j = N, in Pa} \quad (108)$$

where

$\rho_{mB,j}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

$P_{GB,j}$ pressure change due to change in velocity of the flow in the air supply passage of chimney segment j, in Pa

$w_{mB,j}$ velocity of the supply air based on the average density of the supply air in the chimney segment j, in m/s

The pressure loss $P_{B31,j}$ due to the splitting in the area of the inlet into air supply duct of the connection pipe j+1 shall be calculated with the following formula:

$$P_{B31,j} = \varsigma_{B31,j+1} \cdot \frac{\rho_{mB,j+1}}{2} \cdot w_{mB,j+1}^2 \text{ for j < N, in Pa} \quad (109)$$

with

$$\varsigma_{\text{B31,j+1}} = 0{,}35 \cdot \left(\frac{\dot{m}_{\text{BV,j+1}}}{\dot{m}_{\text{B,j+1}}} \right)^2 \text{ for j < N} \tag{110}$$

and

$$P_{\text{B31,N}} = 0 \text{, in Pa} \tag{111}$$

where

$P_{\text{B31,j}}$ pressure loss due to the splitting of the air supply in the area of the inlet into the air supply duct of the connection pipe j+1, in Pa

$\rho_{\text{mB,j}}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

$\zeta_{\text{B31,j}}$ flow resistance coefficient due to splitting of the air supply in the area of the inlet into the air supply duct of the connection pipe j+1,

$\dot{m}_{\text{BV,j}}$ mass flow of supply air in the connection pipe j, kg/s

$\dot{m}_{\text{B,j}}$ mass flow of the supply air in the chimney segment j, kg/s

$\rho_{\text{mB,j}}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

15.9.4 Pressure resistance of the air supply duct of the connection pipe j ($P_{\text{RBV,j}}$)

The pressure resistance of the air supply duct of the connecting pipes j $P_{\text{RBV,j}}$ shall be calculated with the following formula:

$$P_{\text{RBV,j}} = S_{\text{EB}} \cdot \left(\psi_{\text{BV,j}} \cdot \frac{L_{\text{V,j}}}{D_{\text{hBV,j}}} + \sum \varsigma_{\text{BV,j}} \right) \cdot \frac{\rho_{\text{mBV,j}}}{2} \cdot w_{\text{mBV,j}}^2 + S_{\text{EMBV,j}} \cdot P_{\text{B32,j}} + S_{\text{EGBV,j}} \cdot P_{\text{GBV,j}} \text{, in Pa} \tag{112}$$

where

$P_{\text{RBV,j}}$ pressure resistance of the air supply duct of the connecting pipes j, Pa

$P_{\text{B32,j}}$ pressure loss due to the splitting of the air supply in the area of the inlet into the connecting air supply duct of the chimney segment j+1, in Pa

$P_{\text{GBV,j}}$ pressure change due to change in velocity of the flow in the air supply passage of the connection pipe j, in Pa

$\psi_{\text{BV,j}}$ coefficient of friction of the air supply passage of the connection pipe j

$L_{\text{V,j}}$ length of the connection pipe j, in m

$D_{\text{hBV,j}}$ hydraulic diameter of the air supply passage of the connection pipe j, in m

$\Sigma\zeta_{\text{BV,j}}$ sum of coefficients of flow resistance in the air supply passage of the connection pipe j,

$\rho_{\text{mBV,j}}$ density of the supply air averaged over the length of the connection pipe j, in kg/m^3

$w_{\text{mBV,j}}$ velocity of the supply air based on the average density of the supply air in the connection pipe j, in m/s

S_{EB} flow safety coefficient for the air supply duct

$S_{\text{EMBV,j}}$ flow safety coefficient for the pressure resistance due to splitting of the air supply into the connection pipe j ($S_{\text{EMBV,j}} = S_{\text{EB}}$ for $P_{\text{B32,j}} \geq 0$ and $S_{\text{EMBV,j}} = 1{,}0$ for $P_{\text{B32,j}} < 0$)

$S_{\text{EGBV,j}}$ flow safety coefficient for the pressure resistance due to change of flow velocity in the connection pipe j ($S_{\text{EGBV,j}} = S_{\text{EB}}$ for $P_{\text{GBV,j}} \geq 0$ and $S_{\text{EGBV,j}} = 1{,}0$ for $P_{\text{GBV,j}} < 0$)

The change of pressure due to change of the flow velocity in the air supply duct of the connection pipe j $P_{GBV,j}$ shall be calculated with the following formula:

$$P_{GBV,j} = \frac{\rho_{mBV,j}}{2} \cdot w_{mBV,j}^2 - \frac{\rho_{mB,j}}{2} \cdot w_{mB,j}^2 \text{ , in Pa} \quad (113)$$

where

$P_{GBV,j}$ pressure change due to change in velocity of the flow in the air supply passage of the connection pipe j, in Pa

$\rho_{mBV,j}$ density of the supply air averaged over the length of the connection pipe j, in kg/m^3

$\rho_{mB,j}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

$w_{mBV,j}$ velocity of the supply air based on the average density of the supply air in the connection pipe j, in m/s

$w_{mB,j}$ velocity of the supply air based on the average density of the supply air in the chimney segment j, in m/s

The pressure loss $P_{B32,j}$ due to the splitting of the air supply in the area of the inlet into the air supply duct of the connection pipe j shall be calculated with the following formula:

$$P_{B32,j} = \varsigma_{B32,j} \cdot \frac{\rho_{mB,j}}{2} \cdot w_{mB,j}^2 \text{, in Pa} \quad (114)$$

with

$$\varsigma_{B32,j} = \left[1 - 0{,}3 \cdot \left(\frac{A_B}{A_{BV,j}}\right)^{0,27} \cdot \left(\frac{\dot{m}_{BV,j}}{\dot{m}_{B,j}}\right)^{0,11}\right] \cdot \left[1 - 2 \cdot \frac{\dot{m}_{BV,j}}{\dot{m}_{B,j}} \cdot \frac{A_B}{A_{BV,j}} \cdot \cos\gamma_{,j} + \left(\frac{\dot{m}_{BV,j}}{\dot{m}_{B,j}} \cdot \frac{A_B}{A_{BV,j}}\right)^2\right] \quad (115)$$

where

$P_{B32,j}$ pressure loss due to the splitting of the air supply in the area of the inlet into the connecting air supply duct of the chimney segment j+1, in Pa

$w_{mB,j}$ velocity of the supply air based on the average density of the supply air in the chimney segment j, in m/s

$\rho_{mB,j}$ density of the supply air averaged over the length of the chimney segment j, in kg/m^3

A_B cross-sectional area of the air supply passage of the chimney, m^2

$A_{BV,j}$ cross-sectional area of the air supply passage of the connection pipe j, m^2

$\dot{m}_{BV,j}$ mass flow of the supply air in the connection pipe j, kg/s

$\dot{m}_{B,j}$ mass flow of the supply air in the chimney segment j, kg/s

$\gamma_{,j}$ angle of connection between the air supply duct of the connection pipe j and the air supply duct of the chimney segment j

Where a manufacturer supplies the data for his product, these values shall be used.

15.10 Density and velocity of the supply air

15.10.1 Density and velocity of the supply air in the air supply duct averaged over the length of the chimney segment

When calculating a balanced flue chimney with a flue duct with a thermal resistance less than or equal to 0,65 W/m^2K the temperature of the supply air varies and consequently the density needs to be calculated. The density of the supply air in the air supply duct averaged over the length of the chimney segment j $\rho_{mB,j}$ shall be calculated with the following formula:

$$\rho_{mB,j} = \frac{p_L}{R_L \cdot T_{mB,j}} \text{, in kg/m}^3 \qquad (116)$$

where

$\rho_{mB,j}$ density of the supply air in the air supply duct averaged over the length of the chimney segment j, in kg/m^3

p_L pressure of the external air, in Pa

R_L gas constant of the air, in $\frac{J}{kg \cdot K}$

$T_{mB,j}$ temperature of the supply air in the air supply duct of chimney segment j, in K

The velocity of the supply air in the air supply duct averaged over the length of the chimney segment j $w_{mB,j}$ shall be calculated using the following formula:

$$w_{mB,j} = \frac{\dot{m}_{B,j}}{A_{B,j} \cdot \rho_{mB,j}} \text{, in m/s} \qquad (117)$$

where

$w_{mB,j}$ velocity of the supply air in the air supply duct averaged over the length of chimney segment j, in $\frac{J}{kg \cdot K}$

$\dot{m}_{B,j}$ mass flow of the supply air in the air supply duct of chimney segment j, in K

$A_{B,j}$ cross-sectional area of the air supply passage of the chimney segment j, in Pa

$\rho_{mB,j}$ density of the supply air in the air supply duct averaged over the length of the chimney segment j, in kg/m^3

15.10.2 Density and velocity of the supply air averaged over the length of the connection pipes

When calculating a balanced flue chimney with a flue duct with a thermal resistance less than or equal to 0,65 W/m^2K the temperature of the supply air varies and consequently the density needs to be calculated. The density of the supply air averaged over the length of the connection pipe j $\rho_{mBV,j}$ shall be calculated with the following formula:

$$\rho_{mBV,j} = \frac{p_L}{R_L \cdot T_{mB,j}} \text{, in kg/m}^3 \qquad (118)$$

where

$\rho_{mBV,j}$ density of the supply air in the air supply duct averaged over the length of the connection pipe j, in kg/m³

p_L pressure of the external air, in Pa

R_L gas constant of the air, in $\frac{J}{kg \cdot K}$

$T_{mBV,j}$ temperature of the supply air in the air supply duct of the connection pipe j, in K

The velocity of the supply air averaged over the length of the connection pipe j $w_{mBV,j}$ shall be calculated using the following formula:

$$w_{mBV,j} = \frac{\dot{m}_{BV,j}}{A_{BV,j} \cdot \rho_{mBV,j}} \text{, in m/s} \tag{119}$$

where

$w_{mBV,j}$ velocity of the supply air averaged over the length of the connection pipe j, in $\frac{J}{kg \cdot K}$

$\dot{m}_{BV,j}$ mass flow of the supply air in the air supply duct of the connection pipe j, in K

$A_{BV,j}$ cross-sectional area of the air supply passage of the connection pipe j, in Pa

$\rho_{mBV,j}$ density of the supply air averaged over the length of the connection pipe j, in kg/m³

16 Consideration of chimney fans

16.1 General

Chimney fans can be taken into account for calculation of chimneys only if

— the fan operation is controlled by safety device which cuts off all heating appliances in case of fan operation failure or

— there is sufficient proof that there is still a safe operation of all heating appliances in case of fan operation failure.

The pressure gain created by the chimney fan P_{Fan} can be calculated with the following formula:

$$P_{Fan} = \left[c_0 + c_1 \cdot \dot{V}_{Fan} + c_2 \cdot \dot{V}_{Fan}^2 + c_3 \cdot \dot{V}_{Fan}^3 + c_4 \cdot \dot{V}_{Fan}^4\right] \cdot \frac{\rho_{Fan}}{1,2} \text{, in Pa} \tag{120}$$

$$\dot{V}_{Fan} = \frac{\dot{m}_N}{\rho_{Fan}} \text{, in m³/s} \tag{121}$$

$$\rho_{Fan} = \frac{p_L}{R \cdot T_{Fan}} \text{, in kg/m³} \tag{122}$$

where

c_0 is the characteristic value of the chimney fan according to prEN 16475-2, in Pa

c_1 is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)

c_2 is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^2

c_3 is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^3

c_4 is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^4

$\dot{V}_{Fan}$ is the flue gas volume flow at the chimney fan, in m³/s;

ρ_{Fan} is the flue gas density at the chimney fan, in kg/m³;

$\dot{m}_N$ is the flue gas mass flow at the outlet of the chimney, in kg/s;

p_L is the external air pressure (see EN 13384-1:2015, 5.7.2), in Pa;

R is the gas constant of the flue gas (see EN 13384-1:2015, 5.7.3.2), in J/(kg · K);

T_{Fan} is the flue gas temperature at the chimney fan, in K.

The characteristic values of the chimney fan c_0 to c_4 have to be given by the fan manufactures or by the literature.

NOTE For a non-permanent used chimney fan the calculation needs to be done without taking into account the pressure gain created by the chimney fan but its flow resistance.

16.2 Inline fans

Inline fans can be taken into account for calculation of chimneys serving more than one heating appliance only if all these heating appliances are connected over one common, single cascade and the fan is situated in the last collector segment NC of this cascade.

Divergent to Formula (49) the theoretical draught available due to the chimney effect of the last collector segment N $P_{HC,N}$ with an inline fan shall be calculated using the following formula:

$$P_{HC,N} = H_{C,N} \cdot g \cdot (\rho_L - \rho_{mC,N}) + P_{Fan}, \text{ in Pa} \quad (123)$$

where

g is the acceleration due to gravity = 9,81 m/s^2;

$H_{C,N}$ is the effective height of the last collector segment N, in m;

ρ_L is the density of the external air, in kg/m^3;

$\rho_{mC,N}$ is the mean density of the flue gas in the last collector segment N, in kg/m^3.

P_{Fan} is the pressure gain created by the inline fan, in Pa;

For negative pressure chimneys the requirements of 14.2.1 and the following relationship shall be verified:

$$P_{Ze} \geq P_B, \text{ in Pa} \quad (124)$$

where

P_{Ze} is the minimum draught required at the flue gas inlet into the chimney, in Pa;

P_B is the pressure resistance of the air supply, in Pa.

NOTE 1 If necessary, the capacity of the inline fan needs to be appropriately reduced.

For positive pressure chimneys the requirements of 14.2.1 and the following relationship shall be verified:

$$P_{ZOe} + P_{HC,N} - P_{RC,N} \leq P_{ZV\ excess}\text{, in Pa} \tag{125}$$

where

$P_{ZOe,}$ is the maximum differential pressure at the flue gas inlet into the chimney, in Pa;

$P_{HC,N}$ is the theoretical draught available due to the chimney effect of the last collector segment N, in Pa;

$P_{RC,N}$ is the pressure resistance of the last collector segment N, in Pa;

$P_{Z\ excess}$ is the maximum allowed pressure from the designation of the chimney, in Pa.

NOTE 2 If necessary, the capacity of the inline fan needs to be appropriately reduced.

For the calculation of the pressure gain created by the inline fan P_{Fan} according Formula (120) normally the following formula can be used:

$$T_{Fan} = T_{eC,N}\text{, in K} \tag{126}$$

where

T_{Fan} is the flue gas temperature at the chimney fan, in K;

$T_{eC,N}$ is the flue gas temperature at the entrance of the last collector segment N, in K.

16.3 Exhaust fans

Divergent to Formula (31) the theoretical draught available due to the chimney effect of the last chimney segment N $P_{H,N}$ with an exhaust fan shall be calculated using the following formula:

$$P_{H,N} = H_{,N} \cdot g \cdot (\rho_L - \rho_{m,N}) + P_{Fan}\text{, in Pa} \tag{127}$$

where

g is the acceleration due to gravity = 9,81 m/s²;

$H_{,N}$ is the effective height of the last chimney segment N, in m;

ρ_L is the density of the external air, in kg/m^3;

$\rho_{m,N}$ is the mean density of the last chimney segment N, in kg/m^3;

P_{Fan} is the pressure gain created by the exhaust fan, in Pa.

For the calculation of the pressure gain created by the exhaust fan P_{Fan} according Formula (120) normally the following formula can be used:

$$T_{Fan} = T_{o,N}\text{, in K} \tag{128}$$

where

T_{Fan} is the flue gas temperature at the chimney fan, in K;

$T_{o,N}$ is the flue gas temperature at the chimney outlet, in K.

Annex A
(informative)

Recommendations

A.1 General

The design of chimneys serving more than one heating appliance needs some experience. Some recommendations are provided here. These recommendations should be taken into account during the calculation if they are relevant.

A.2 Recommendations for the chimney and heating appliances

Heating appliances which are out of action over a longer time period should be closed with shut-off devices or dampers where this is allowed. These devices should be closed during periods when no combustion takes place. In any case, however, doors for the combustion chamber and openings for air supply of the heating appliances should be closed.

A.3 Recommendations for connecting flue pipes

Connecting flue pipes should rise vertically and directly from the appliance outlet towards the chimney. Where the connecting flue pipe does not rise vertically and directly from the appliance outlet its length should not exceed 0,5 m.

The vertically rise directly from the appliance outlet should exceed half of the total length. The total length of the connecting flue pipe should not exceed 2,5 m.

The free cross section of connecting flue pipes should be constant in form and size and have as a minimum the same hydraulic diameter as the flue gas outlet of the heating appliance. In case two heating appliances are connected to a chimney by only one connecting flue pipe, the free cross area of the common pipe section should be calculated according to the calculation method given in this standard regarding the sum of the nominal heat outputs of both heating appliances.

Annex B
(informative)

Characteristics for the heating appliance

In case the factors b_0, b_1, b_2, b_3, b_4 and the factors y_0, y_1, y_2 used in Formulas (10) and (11) are not specified by the manufacturer of the heating appliances Table B.1 should be used in case relevant flue gas values are available; Table B.2 should be used in case no flue gas values are given.

Table B.1 — Specification of flue gas characteristics of heating appliances with available flue gas values

Heating appliance	Working condition	$P_{Wc,j}$					$t_{Wc,j}$		
		b_0	b_1	b_2	b_3	b_4	y_0	y_1	y_2
Heating appliances fired for solid fuels without fan	in operation	0	0	0	0	$P_{W,j}$	$t_{W,j}$	0	0
	out of action	0	0	$P_{W,j}$	0	0	$t_{uV,j}$	0	0
Heating appliances fired for liquid fuels without fan	in operation	0	0	$P_{W,j}$	0	0	$t_{W,j}$	0	0
	out of action	0	0	$P_{W,j}$	0	0	$t_{uV,j}$	0	0
Heating appliances with draught diverters for gaseous fuels	in operation	0	0	$P_{W,j}$	0	0	$t_{uV,j}$	$t_{W,j}$ - $t_{uV,j}$	-1
	out of action	0	0	$P_{W,j}$	0	0	$t_{uV,j}$	0	0
Heating appliances without draught diverters for gaseous fuels with fan	in operation	-$P_{WG,j}$	0	$P_{W,j}$ + $P_{WG,j}$	0	0	$t_{W,j}$	0	0
	out of action	0	0	$P_{W,j}$ + $P_{WG,j}$	0	0	$t_{uV,j}$	0	0

where

$t_{uV,j}$ ambient air temperature of the boiler room

$t_{W,j}$ flue gas temperature of the appliance j

$P_{W,j}$ minimum draught for the heating appliance j

$P_{WG,j}$ guaranteed pressure difference created by the fan at nominal heat output

NOTE $P_{W,j}$ could be the smallest value where the heating appliance still works correctly as declared by the manufacturer. $t_{W,j}$ and $\dot{m}_{W,j}$ shall correspond to this value.

Table B.2 — Specification of flue gas characteristics of heating appliances without available flue gas values

Heating appliance	**Working condition**	$P_{Wc,j}$					$t_{Wc,j}$			$\dot{m}_{W,j} / Q_{N,j}$	$(CO_2)_{W,j}$
		b_0 in Pa	b_1 in Pa	b_2 in Pa	b_3 in Pa	b_4 in Pa	y_0 in °C	y_1 in °C	y_2 in °C	in g/(s·kW)	in %
Heating appliances fired for solid fuels without fan	in operation	0	0	0	0	12	250	0	0	1,2	8,1
	out of action	0	0	13,5	0	0	$t_{uV,j}$	0	0	1,2	0
Heating appliances fired for liquid fuels without fan	in operation	0	0	9	0	0	$t_{W,j}$	0	0	0,85	7,0
	out of action	0	0	13,5	0	0	$t_{uV,j}$	0	0	0,85	0
Heating appliances with draught diverters for gaseous fuels	in operation	0	0	3,1	0	0	$t_{uV,j}$	130- $t_{uV,j}$	0	0,84	5,4
	out of action	0	0	3,6	0	0	$t_{uV,j}$	0	0	0,84	0
Heating appliances without draught diverters for gaseous fuels with fan	in operation	-50	0	50	0	0	$t_{W,j}$	0	0	–	–
	out of action	0	0	50	0	0	$t_{uV,j}$	0	0	–	–

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